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The Equal Tempered Musical Scale

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IN almost all elementary physics texts it is stated that the chief reason for the employment of the tempered scale in music is the prohibitive complexity of keyed instruments so constructed as to provide all the tones of a true scale in every key; in other words, instruments able to play in a just intonation. It is not emphasized sufficiently that the performance of modern music would be quite impossible even if players could be found to manipulate such instruments.

Modern music, in the sense the term is here used, means most of our (European) music since the end of the 17th century. Bach (1685–1750), the great protagonist of the movement for the introduction of the equal temperament, wrote a series of compositions for the "well-tempered clavichord" through all the keys as a demonstration of its possibilities. The point to be emphasized is that the requirement of harmonic composition, as distinguished from the earlier melodic writings, made some kind of a compromise imperative. Without the freedom of modulation assured by the identity of a *C* sharp with the adjoining *D* flat, to give a simple illustration, musical composition would have been seriously retarded in its development and would never have attained the great variety and richness of coloring it now possesses.

Perhaps all of this is fairly well known, though usually ignored in the discussion of temperament in physics texts, but there are certain more fundamental difficulties connected with just intonation that may not be so familiar. It may be worth while to call attention to them in order to emphasize the fact just mentioned, that it is not so much the mechanical difficulties involved in instruments constructed for just intonation as the demands made by a rapidly developing art, that made the retention of a just intonation impossible. More than that, it is a fact that just intonation contains within itself some curious inconsistencies, which are by no means negligible elements in the question of its suitability for harmonic composition. A number of these will be taken up here.

Just intonation signifies, of course, the pitch given by the tones of the modern diatonic scale, which is reproduced in Table I for reference. For numerical convenience, the relative frequencies are denoted by the small numbers in the first line. The last line contains the frequencies of the equal tempered scale referred to *C*. Note the two *different* whole tone intervals, 9/8 and 10/9. Their ratios differ by 81/80; that is, $90/80 \div 90/81$. This small difference is appreciable; it is known as a *syntonic comma*. Any frequency falling outside of the range of the table can easily be brought within it (for identification and com-

TABLE I. *The major diatonic scale.*

Frequency	24	27	30	32	36	40	45	48
Name	*C*	*D*	*E*	*F*	*G*	*A*	*B*	*C'*
Ratio to *C*	1	9/8	5/4	4/3	3/2	5/3	15/8	2
Ratio to next lower tone		9/8	10/9	16/15	9/8	10/9	9/8	16/15
Ratio to *C* (tempered scale)	1.0000	1.12246	1.25992	1.33484	1.49831	1.68179	1.88775	2

FIG. 1.

parison) by the simple device of multiplying or dividing by some integral power of 2.

It may surprise some readers to learn that the open strings of a violin, though accurately tuned in fifths, are not "in tune" in the sense of belonging to the tones of their true scale. An interval of a fifth corresponds to a frequency ratio of 3/2. Thus the violin strings *G*, *D*, *A*, *E* have the frequencies 18, 27, 40.5, 60.75, beginning for convenience with *G* as 18, an octave below the *G* in Table I; the frequencies of the three higher strings are found by successive multiplication by 3/2. It is seen that the *A* is higher by 0.5 than the "true" *A*, which is 40; also the *E* is 60.75. instead of 2×30 or 60. To put the matter in another way,[1] let a violinist play the chord in Fig. 1 in perfect tune on an accurately tuned violin. The high *E* is to be played with the fourth finger on the *A* string exactly an octave above the lower *E*, which in turn is a true sixth (ratio 5/3) above the *G* (open string). It will be found that the high *E* is lower in pitch than the open *E* string (denoted by the superscript 0) by an amount equal to a syntonic comma. For the frequencies corresponding to the chord are 18, 30 and 60, whereas the *E* string has a frequency of 60.75, as we have just seen; the difference is 6075/6000, or 81/80, which is the syntonic comma. As a matter of fact, in the just scale we see that the *A* and *D* next below are not in the ratio of 3/2, as a perfect fifth should be.

Incidentally the Pythagorean scale was built up by means of a succession of fifths. Its interval ratios are 1, 9/8, 81/64, 4/3, 3/2, 27/16, 243/128, 2. It is noteworthy that it does not primarily contain the octave, but, on progressing upward by successive multiplication by 3/2 (as in the case of the violin strings), arrives at a "near" octave. Thus $(3/2)^{12}=129.75$ (very nearly), whereas the nearest true octave is $2^7=128$. The comparison is more strikingly shown in Fig. 2, called the "fifth circle."[1] This slight difference is known as the *Pythagorean comma;* it is evidently 129.75/128, or very nearly 74/73. Like the syntonic comma, it is appreciable. However, the difference between the two commas is said to be on the threshold of detectability by the most acute human ear. The ratio value of this "schisma" is about 887/886.

To take another instance of the inner lack of consistency of the diatonic scale, consider the series of triads in Fig. 3, each perfectly in tune and in correct harmonic progression.[1] The initial and final chords are both *C*-major triads, and each chord has one or two tones in common with the next preceding one. The remaining tones of the chord are determined (according to the intervals of just intonation) by means of the tone that persists. Though each is thus "in tune," the final triad is found to be lower, by a perceptible amount (a syntonic comma), than the initial one. This effect, by the way, is connected with the fact that in the third chord, the interval from *D* to *A* is not a true fifth, as was noted before, so that if this triad is to remain "pure," the *D* must be lowered a comma. This can be avoided only by relinquishing the principle of harmonic purity. It will not do to leave the *A* as it is in the scale; the effect of a fifth that much out of tune is too disagreeable.

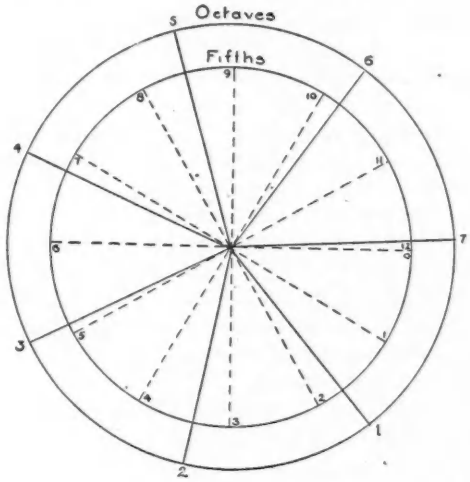

FIG. 2. The "fifth circle."

[1] Jonquière, *Grundriss der Musikalischen Akustik*, Th. Grieben's Verlag (L. Fernau), 1898.

These illustrations show clearly the fundamental and inherent impasse encountered when we attempt to use the same scale for both melody and harmony. Yet even this is not the whole of the difficulty. Two more items may be briefly touched upon, commonplace enough, but rarely noticed. Accidentals must be introduced when we construct our just scales on other tones of the octave. Without going into the tabulation of their frequencies, it suffices to say that more than one *C* sharp is obtained, depending upon what tone is considered as the tonic of the scale. The same is true of the "flats." Then, of course, we may base other scales on these new tones as tonics, and thus introduce double sharps and double flats. If we decide to ignore all differences of the magnitude of a comma, we can get along with one *C* sharp and one *D* flat (to mention only these two as illustrations, the *D* flat being higher than the *C* sharp) and thus have 22 tones within the octave. A scale really approximating ideal conditions would require over fifty steps, whereas the next real improvement would be attained only by something over three hundred steps. As was stated in the beginning, such scales could not be used to interpret modern music. What would be the effect on the hearer if a player, in the transition from one chord to the other in Fig. 4, should suddenly raise his pitch from the *C* sharp to the *D* flat by an amount corresponding to a difference of 2 to 4 percent? It is well known, of course, that it is just this identity of *C* sharp and *D* flat in the equal tempered scale that increases the flexibility and possibilities of modulation from one key to the other. This recourse to the tempered scale is not to be looked upon as a distasteful compromise, but as a device which is an essential and indispensable factor in our modern musical structure.

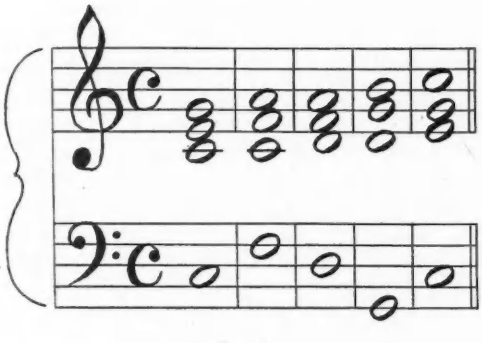

FIG. 3.

FIG. 4.

FIG. 5.

It is true that a violin or voice can, and some times does, execute a melody or (in the case of the violin) a series of chords, e.g., a series of thirds, more nearly as required by the diatonic scale than can, say, a piano, in which the only true intervals are the octaves. Such a real compromise is unavoidable. One is reminded of the mutually incompatible conditions that a lens must satisfy to form a perfect image.

As a matter of fact, a violinist employs tones sanctioned by neither the true nor the tempered scale. Consider Fig. 5. Here the player or singer will sound the *C* sharp as closely as possible to the *D*. The former is a "passing" note, and a musical ear instinctively demands as close an approach as possible to the keynote, *D*. On the other hand, a *D* flat, as a passing note, would be very close to *C* in a *C* major chord. But we have just seen that *D* flat is ***higher*** in pitch than *C* sharp. What is to be done about it? We are again faced with the fact that tones appear in a dual rôle, as an element in melody and in harmony. It is furthermore a question whether the differences between the just and equal temperament are not less than the very slight differences in pitch, due to a variety of causes, among the instruments of a large orchestra. This remark applies also to the slight variations in pitch of the voice. For a modern orchestra, at least, the tempered scale is indispensable.

It is sometimes remarked in physics texts that the performance of music in just intonation would offer no difficulty to a string instrument player, since he can vary the pitch of tones at will. This he might do in certain restricted instances. We have already seen what happens even in such cases where he is at liberty to choose his own pitch. To use our stock example again, he

would not know to what scale a given *C* sharp belonged; even the composer could not tell him in many instances. Just what the player will do will be decided by his intuition as a musician; the tone may be part of a scale (or melody), an element of a chord (he will want to play his thirds and fifths in tune!) or it may be only a passing tone.[2]

A great deal of ingenuity has been expended on the construction of fixed tone instruments designed to provide a just intonation. Prominent among these is the experimental harmonium of Helmholtz,[3] with 30 tones in the octave. But Helmholtz states that it is necessary at times to make an enharmonic change, which "perceptibly alters the pitch"; for example by the syntonic comma 81/80. Again he remarks that "in most cases it is possible to transpose the music to be played on such instruments, so as to avoid the necessity of making these enharmonic changes, provided the modulations do not extend too far into different keys." He seems to deprecate the "immoderate use of striking modulations" on the part of modern composers and thinks it is too easy a means for making their output "piquant and highly colored." It is highly doubtful that composers will relinquish this means of enriching their products.

The object of these justly-intoned instruments is, of course, to obtain chords in their harmonic purity, particularly the triads. Jonquière,[1] and others in like vein, speaks of the "captivating effect of the absolute, untroubled euphony of a pure major triad" as the reason why most theorists who have been interested in the matter had the firm conviction that this triad should be the basis of all future development. But the unavoidable conclusion is that the scale does not exist which is perfectly adequate to every musical purpose. As has been mentioned previously, the demands of melody and harmony, especially with regard to modern modulations, are incompatible. The same author expresses the situation picturesquely when he writes, "In music, and particularly in the polyphonic-harmonic music of modern times, melody and harmony, though fundamentally and essentially different, go hand in hand in unity. The tempered system is, as it were, a neutral ground in which the two sisters are always in accord and never get into conflict with each other. To violate this neutrality would mean to invoke a war which could after all, end only in a renewed recognition of this neutrality."

[2] The author is indebted to Professor P. G. Clapp, Department of Music, University of Iowa, for the following pertinent comment: "My observations suggest that, in most performance, a sensitive ear tolerates an extraordinary amount of unjust intonation without being consciously disturbed, although even the average ear apprehends and enjoys the genuine sympathetic resonance which occurs when a performance is relatively free from these foreign elements. As to the deliberate modification of pitch common in the intentional use of non-harmonic tones as dissonant embellishments, I am perfectly sure that the trained ear regards these as melodic and dissociates them from even such harmony as may at the moment be audible. It is astonishing that the same individual can *simultaneously* judge a chord on its approximation of just intonation, a major or minor interval in the chord on its modification of just intonation to emphasize tendency and progression, and a foreign tone purely as an embellishment without the thought of referring it to any harmonic value at all; yet every cultivated musical listener does this constantly without conscious effort. Any adequate system of aesthetics must recognize these factors, and the science of acoustics may render a great service to aesthetics and art by ascertaining and recording what actually happens in this complex situation."

[3] Helmholtz, *Sensations of Tone*, Longmans, Green and Co., 1875.

SCIENCE seems to me to teach in the highest and strongest manner the great truth which is embodied in the Christian conception of entire surrender to the will of God. Sit down before fact as a little child, be prepared to give up every pre-conceived notion, follow humbly wherever and to whatsoever abysses Natu e leads, or you shall learn nothing. I have only begun to learn content and peace of mind since I have resolved, at all risks, to do this.—HUXLEY.

What Are Physical Dimensions?

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PROBABLY few subjects in physics suffer so much from early misconceptions as dimensional analysis. The student is introduced to the idea of the dimensions of a physical quantity in his first courses and almost from the beginning the subject comes to be surrounded with an air of mystery. This arises largely from the fact that the meaning of the dimensional formulas for quantities is not made clear. The student learns to write such equations as

$$1 \text{ e.s.u. charge} = 1 \text{ g}^{\frac{1}{2}} \cdot \text{cm}^{\frac{1}{2}} \cdot \text{sec.}^{-1} \qquad (1)$$

and to use them in changing units. Since these equations are used in exactly the same way as, for example,

$$1 \text{ ft.} = 12 \text{ in.}, \qquad (2)$$

he naturally supposes that they are of the same nature. Eq. (2) is an equation between units; that is, between concrete physical quantities. But if one tries to regard Eq. (1) as an expression for a unit charge in terms of grams, centimeters and seconds, he is led to fruitless speculations about such things as the meaning of the "square root of a gram." The point of view of this article will be that Eqs. (1) and (2) are essentially different and that Eq. (1), properly speaking, is not an equation between *units* at all.

The air of mystery is deepened when the student learns that physical equations are dimensionally homogeneous, that transcendental functions appear with dimensionless arguments and that these facts may be used to check a derivation or even sometimes to anticipate the result. He wonders what is the reason for this. It is true that these properties of equations are commonly regarded as self-evident, the reason given being that arithmetic operations such as *log* or *sin* have a meaning only when applied to numbers. However, as Bridgman has pointed out, it would be quite possible to describe the motion of a falling body by the equation

$$\sin v \cos gt - \cos v \sin gt = 0, \qquad (3)$$

which is simply the sine of the usual

$$v - gt = 0. \qquad (3')$$

We might even combine Eqs. (3) and (3′) into

$$v - gt + \sin(v - gt) = 0 \qquad (4)$$

and thus obtain an equation that is perfectly true, in that it is satisfied by the values of v, g and t throughout the motion; yet it violates not only our ideas about transcendental functions but also the principle of homogeneity. Evidently we cannot reject such equations as meaningless. Why is it then that they do not arise naturally?

We shall find that these questions are answered by certain considerations about the kinds of quantities used in physics and about the way units are interrelated. Such questions have been discussed at length in Bridgman's excellent book[1] on the subject and the present article is written simply for the purpose of making these ideas better known. Its object will be to explain briefly the fundamental ideas of the subject, and to show how they lead to a supplementary method of analysis. No attempt will be made to cover all the ramifications of dimensional analysis. In particular, the extensive applications to engineering problems will not be touched upon.

One of the most obvious characteristics of measurement is that it is in terms of units. The result of a measurement is expressed by a number q and a unit $[Q]$. If we adopt a different unit, the numerical measure changes and, in fact, varies inversely as the size of the unit. But the ratio q/q' of two quantities of the same kind is independent of the unit. This means that in saying that one quantity is twice as great as another, one does not need to specify the unit. Bridgman calls this property *the absolute significance of relative magnitude* and for our purposes it is the fundamental property of physical quantities.

It is not always clear that a quantity is measured directly in terms of a unit. Certainly the process of measurement does not always consist in a comparison with a unit quantity of the same kind. More often than not, quantities are measured indirectly; that is, calculated from

[1] P. W. Bridgman, *Dimensional Analysis*, Revised Edition, Yale Univ. Press, 1931. Much of the material here presented has been drawn from this book.

measures of other quantities. Also there are quantities like index of refraction and specific gravity, which are simply numbers and hence do not require the specification of a unit. But the quantities that are measured directly, and from which the others are calculated, are measured in terms of units and the proposition that *the ratio of two quantities of the same kind is independent of the units employed* is true for all physical quantities.

It should be noticed that this property is not a necessary consequence of measurement in its most general sense. We might define a quantity $q = \log l$, where l is the measure of a length. This would be a perfectly legitimate physical quantity, in the sense that it is a number assigned as the result of a definite sequence of physical and mathematical operations, but it would not satisfy the foregoing requirement. The restriction of quantities to those that have this property is a definite limitation. We shall see that it has the effect of insuring that in any change of units, all quantities are changed at most by a factor. This kind of change is characteristic of a change of unit and so it is convenient to express a derived quantity in terms of a unit, even though the unit plays no direct rôle in the process of measurement. For example, the units of acceleration, torque or viscosity do not enter into the process of measuring these quantities.

If a set of quantities is connected by a relation, the units cannot be chosen arbitrarily. The equation $f = ma$ requires that the units of force, mass and acceleration be interrelated. If, however, we insert a constant k and write $f = kma$, the units may be made independent. Similarly, the equation $W = (4.2)(10^7)H$ relating heat and work can be made independent of the units by writing it in the form $W = JH$. The process of inserting a constant amounts to introducing a new quantity defined by the equation. Throughout dimensional analysis physical constants are treated in the same way as other physical quantities. We see that the independence of units is closely connected with the appearance of constants. In fact, any equation can be made independent of the units by inserting a constant along with each quantity entering and by making it change inversely as that quantity when the units are changed.

We need now to make a fundamental distinction. We suppose that we have a system of equations and that all the quantities entering may be measured directly, or else calculated from the others by equations of the system. Quantities such that the units may be chosen independently and such that all other quantities entering can be calculated from them by equations of the system, we shall call a set of fundamental quantities for the system of equations. The other quantities will be called derived. For example, it is customary to take mass, length and time as a fundamental set for the equations of mechanics.

We note first that the fundamental set need not be unique. Force, length and time would be equally suitable as fundamental quantities for mechanics. But the *number* is fixed by the system of equations, for each set must be expressible in terms of any other.

Secondly, the fundamental set is relative to a system of equations. If we include more equations, the number of fundamental quantities may be changed. Thus the inclusion of the equations of heat phenomena, in the system considered, enables us to add temperature to the fundamental set, and quantity of heat also, unless the first law has been simplified to $W = H$. Likewise, the number of fundamental quantities may be changed by inserting or dropping constants. We have already seen that force can be made independent by putting a force constant in $f = ma$ and in all equations depending on this law. Thus the distinction is not hard and fast but depends on how we write our equations and define our quantities.

In the applications of dimensional analysis the idea of the system of equations takes the form of the system applying to a problem. It consists of all equations one would need in solving the problem. In special cases it may be possible to choose unconventional fundamental sets. For example, Bridgman[2] has shown that in Stokes' problem of a sphere falling slowly through a viscous fluid, force may be taken as fundamental, in addition to mass, length and time. This is possible because the equation $f = ma$ does not apply, the problem involving only unaccelerated motion.

[2] Reference 1, p. 65.

The fact that the quantities we use satisfy the requirement of the absolute significance of relative magnitude and the fact that our equations are independent of certain units form the basis of a brief mathematical theory. The assumption that a quantity q can be calculated from measures of the fundamental quantities is expressed by

$$q=f(l_1\cdots l_p, m_1\cdots m_q, t_1\cdots t_r), \qquad (5)$$

where for definiteness we suppose that length, mass and time have been chosen as fundamental. Quantities defined by derivatives or integrals are limits of expressions of this type and offer no difficulty. The requirement that the ratio of two q's be independent of the size of the fundamental units is expressed by

$$\frac{f(l_1\cdots l_p, m_1\cdots m_q, t_1\cdots t_r)}{f(l_1'\cdots l_p', m_1'\cdots m_q', t_1'\cdots t_r')} = \frac{f(\lambda l_1\cdots \lambda l_p, \mu m_1\cdots \mu m_q, \nu t_1\cdots \nu t_r)}{f(\lambda l_1'\cdots \lambda l_p', \mu m_1'\cdots \mu m_q', \nu t_1'\cdots \nu t_r')}.$$

This is an identity and we can therefore differentiate with respect to λ, μ, ν and then put these equal to unity. This yields Euler's equation for homogeneous functions and we have *Theorem* I: *The function f in Eq. (5) is homogeneous in the l's, m's, and t's, respectively.* We now lay down the following *Definition: The degrees α, β, γ of the homogeneous function f in each kind of fundamental quantity are called the dimensions of q with respect to these quantities.* This is simply a formulation of the actual procedure one uses in finding the dimensions of a quantity. The importance of the fact that physical quantities satisfy the requirement of the absolute significance of relative magnitude is now clear, for it is this fact that yields Theorem I and the definition. Only for such quantities are dimensions defined.

Let q become Q when the fundamental units are divided by λ, μ, ν. From the definition of a homogeneous function,

$$Q=f(\lambda l_1\cdots \lambda l_p, \mu m_1\cdots \mu m_q, \nu t_1\cdots \nu t_r) = \lambda^\alpha\mu^\beta\nu^\gamma f(l_1\cdots l_p, m_1\cdots m_q, t_1\cdots t_r).$$

We state this as *Theorem* II: $Q=\lambda^\alpha\mu^\beta\nu^\gamma q$. This tells us that if the measures of the fundamental quantities are multiplied by λ, μ, ν, we must multiply q by

$$\sigma=\lambda^\alpha\mu^\beta\nu^\gamma. \qquad (6)$$

But since the units vary inversely as the numerical measures, this can equally well be interpreted as an equation between the factors by which *units* are multiplied. It is convenient to express the implied dependence of the size of $[Q]$ on $[L]$, $[M]$, $[T]$ by writing $[Q]=[L]^\alpha[M]^\beta[T]^\gamma$. Because of Eq. (6), this furnishes a convenient device for changing units. But we must remember that it means nothing more than Eq. (6). Strictly speaking, a dimensional formula is not an equation between *units* but an equation between *conversion factors*, which we find it convenient to write *as if* it were an equation between units. The question as to the meaning of the "square root of a gram" does not arise, for the exponent $\frac{1}{2}$ in Eq. (1) does not operate on the "g" but only on a numerical factor which we insert next to the "g" when we wish to change units.

The most interesting problem in the mathematical theory is that of finding the restriction imposed by requiring that an equation be independent of the fundamental units. The problem is: What must be the form of an equation

$$f(q_1\cdots q_n)=0 \qquad (7)$$

if it is to be invariant under the transformation

$$Q_k=\lambda^{\alpha_k}\mu^{\beta_k}\cdots\rho^{\gamma_k}q_k, \quad k=1, \cdots, n, \qquad (8)$$

where we are no longer assuming only three fundamental quantities and where the q's are understood to include any dimensional constants that enter.

Now in order that the *equation* be invariant, it is not necessary that the *function* f be unchanged. But there is no restriction in supposing f to be unchanged, for if the equation is invariant it can be rewritten so that the function is absolutely invariant. Supposing this done, we have $f(Q_1\cdots Q_n)=f(q_1\cdots q_n)$ identically in $\lambda, \mu, \cdots, \rho$. Differentiating with respect to these and putting them equal to unity, we obtain a set of partial differential equations in f. The general solution consists of an arbitrary function of any $n-m$ independent solutions, where m is the number of independent equations in the set. The number m is generally equal to the number of independent units but is more precisely defined as the rank of the matrix of the dimensions of the q's. It is easily shown that the $n-m$ solutions may be taken as a set of dimensionless products; that is, expressions

of the form $\Pi = q_1^{a_1} q_2^{a_2} \cdots q_n^{a_n}$, where the a's are selected so as to satisfy

$$\begin{aligned} \alpha_1 a_1 + \alpha_2 a_2 + \cdots + \alpha_n a_n &= 0 \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot & \\ \tau_1 a_1 + \tau_2 a_2 + \cdots + \tau_n a_n &= 0. \end{aligned} \tag{9}$$

The Π's are not unique for there are an infinite number of fundamental sets of solutions of Eqs. (9).

We formulate our conclusion as the Π-*theorem*: *If Eq.* (7) *is invariant under the transformation* (8), *it is possible to write it in the form*

$$F(\Pi_1, \cdots, \Pi_{n-m}) = 0, \tag{10}$$

where the Π*'s are any set of independent dimensionless products of the* q*'s, and* m *is the number of independent units (or the rank of the matrix of the dimensions of the* q*'s).*

If we solve for one of the Π's we obtain the alternative form

$$q_1 = q_2^{b_2} q_3^{b_3} \cdots q_n^{b_n} \Phi(\Pi_2, \cdots, \Pi_{n-m}). \tag{11}$$

It should be noticed that the theorem does not assert that an equation which is independent of the units *must* have the form of Eq. (10) but merely that it *may be written* in this form. An equation such as (4) does not violate the theorem; for, since it is independent of the units, it may be written $v/gt - 1 = 0$.

The Π-theorem furnishes the complete answer to the questions raised at the outset. Transcendental functions have dimensionless arguments because Eq. (10) shows that only such arguments need appear. The principle of dimensional homogeneity is expressed by Eq. (11). We notice that the explanation of both of these facts has nothing to do with the *physical meaning* of the equations. Both are simply consequences of the fact that our equations are written so as to be independent of certain units and this is to a large extent an arbitrary matter. We have seen that any equation can be made independent of the units by inserting constants.

We write the law of gravitation $f = Gmm'/r^2$ but we write Coulomb's law for a vacuum $f = ee'/r^2$. Why do we include a constant in one but not in the other? Logically, we would be as justified in using the law of gravitation to define mass as we are in using Coulomb's law to define charge. Apart from the practical consideration that G is difficult to measure, the only reason for not dropping it is that we want to keep the units of length, mass and time independent and to retain the usual definitions.

However, it is not necessary that we should do this. In fact, Planck[3] has proposed a system of "natural units" so chosen that the gravitational constant, the velocity of light, the quantum and the gas constant are all unity. The equations of physics written in this system of units would have no fundamental quantities. As a whole, they would not be homogeneous on any system of dimensions! The possibility of writing our equations in this form disposes finally of the view that regards dimensional homogeneity as self-evident. Of course, independent units could be found for sub-groups of equations, so that dimensional analysis would still be applicable to them and, in fact, could do everything it is able to do now.

One might object that in choosing units so that the velocity of light, for example, is always unity, we have not really changed its dimensions but merely "suppressed" them and that c remains a velocity even though it is equal to unity and has apparently disappeared. Of course c is a velocity and has the dimensions of velocity but *in this system of equations* velocity has *zero dimensions*. The dimensions of a quantity are relative to a system of equations and definitions and if we define our quantities so that c will always have the value unity, there is no contradiction in saying that c is a velocity and also a pure number.

While it is quite proper to emphasize the element of arbitrariness in the number of independent units and, hence, in the dimensions of a quantity, we should also recognize that there is a sense in which some quantities may be said to have "absolute dimensions." Quantities that are essentially derived, rather than fundamental, may be said to have absolute dimensions in terms of the immediate quantities involved in their definitions. Thus electric intensity has the dimensions of force per unit charge and no one would think of inserting a constant so as to make it independent. Likewise density has the dimensions of mass per unit volume, velocity of length per unit time and viscosity of force per

[3] Planck, *Theory of Heat Radiation*, Eng. tr. by Masius, 1914, p. 174.

unit area per unit velocity gradient. But the dimensions even of these in terms of other quantities are somewhat arbitrary and, in fact, they would all be pure numbers in the system of measurement we have just been considering. On the other hand, quantities like heat, temperature, electric charge and force, which were originally fundamental quantities, cannot be said to have any intrinsic dimensions. They have been *assigned* dimensions in order to simplify certain equations. The arbitrary character of the dimensions of electrical quantities has been pointed out by Birge[4] in a recent article in this journal.

Thus far we have been considering the *theory* of dimensions. We turn now to dimensional *analysis*, and we shall give one or two examples to show how the ideas we have developed lead to a supplementary method of deriving equations. The applications of the Π-theorem depend on a simple observation: if we start from a system of equations that are independent of certain units, any equation we deduce from them must also be.

As a first illustration consider the Child-Langmuir equation for a space-charge-limited current of ions. Consider two electrodes at potentials zero and V_0. We suppose an unlimited number of ions on the electrode $V=0$, starting with negligible initial velocities. The equations applying to the problem are Poisson's equation and the energy equation,

$$\nabla^2 V = -4\pi\rho \quad \text{and} \quad \tfrac{1}{2}mv^2 + eV = 0. \tag{12}$$

We have also the definitions of current density and current,

$$\mathbf{j} = \rho\mathbf{v} \quad \text{and} \quad i = \int \mathbf{j}\cdot d\mathbf{S}, \tag{13}$$

and the boundary conditions

$$\begin{aligned} V &= \partial V/\partial n = 0 \quad \text{over one electrode;} \\ V &= V_0 \qquad\qquad\ \text{over the other.} \end{aligned} \tag{14}$$

The problem is to find an expression for i in terms of V_0 and the quantities specifying the electrodes, which enter through the boundary conditions.

The case of parallel plate electrodes may be found worked out in textbooks[5] on electricity and the result is $i=(1/9\pi)(2e/m)^{\frac{1}{2}}V_0^{\frac{3}{2}}A/D^2$, where D is the separation of the plates and A the area, assumed large compared to D. The cases also of cylindrical and spherical electrodes have been worked out and in all these cases i is proportional to $V_0^{\frac{3}{2}}$. This suggests that this part of the law may be true for electrodes of any shape. The problem of finding the solution for complicated electrodes would be prohibitively difficult but here dimensional analysis comes to our aid. We may suppose the electrodes specified by a linear dimension l and the ratios $r_1 \cdots r_s$, to l, of the other lengths needed to determine them. We expect a relation connecting i, V_0, e/m, l, $r_1 \cdots r_s$. The equations have been written in e.s.u. and so we may take L, M, T as fundamental. We may regard the complete system of equations as including the ultimate definitions of all the quantities involved or we may verify directly that the equations we have written are independent of these units. The quantity e/m is the only dimensional constant entering because it is the only one which appears in Eqs. (12) and (13). If the expected relation is deducible from these equations and conditions (14), it must have the form specified by the Π-theorem. By using the customary dimensional formulas, we easily find a set of dimensionless products and Eq. (11) enables us to state the result

$$i = V_0^{\frac{3}{2}}(e/m)^{\frac{1}{2}}\Phi(r_1 \cdots r_s),$$

which tells us that for electrodes of any shape, i is proportional to $V_0^{\frac{3}{2}}$ and independent of the size of the electrodes. Our dimensional analysis gives no information as to how i depends on the shape of the electrodes, the function Φ being entirely indeterminate.

As another example, consider a problem of Lord Rayleigh,[6] that of finding the rate of heat transfer h from a body immersed in a fluid moving with velocity v. The quantity h will depend on v and on the temperature difference θ between the body and fluid, the thermal conductivity K of the fluid, its heat capacity c per unit volume, the linear dimension l of the body, and the shape factors. Rayleigh took length, time, quantity of heat and temperature as funda-

[4] R. T. Birge, Am. Phys. Teacher **2**, 41 (1934).
[5] For example, Page and Adams, *Principles of Electricity*, 1931, p. 296.
[6] Rayleigh, Nature **95**, 66 (1915).

mental quantities. The Π-theorem then gives the result

$$h = Kl\theta\Phi(lcv/K, r_1 \cdots r_s).$$

This problem is notable because it gave rise to a celebrated controversy. It was pointed out by Riabouchinsky[7] that if one uses only three fundamental quantities, with temperature regarded as having the dimensions of energy, there will be one more dimensionless product. One cannot then conclude, for example, that c and v enter only as cv. This raised the question as to what units are *really* independent, which seems finally to have been settled by Bridgman.[8] The solution lies in recognizing that the question as to whether or not units are independent has a meaning only with reference to a system of equations. The system applying to Rayleigh's problem consists of the equations of heat conduction and in these temperature may be taken as a fundamental quantity. The assignment of the dimensions of energy to temperature rests on considerations concerning molecular phenomena, where temperature enters in the combination $k\theta$. If we define temperature as the energy of a degree of freedom of a molecule, we can eliminate the gas constant k from our equations but there would be no point in using this definition in a problem into which k did not enter. Since Rayleigh's problem was one in heat conduction and not in molecular theory, he was quite justified in taking temperature as fundamental.

These examples suffice to illustrate that a dimensional analysis consists of three steps: the listing of the quantities (including constants) that can enter the proposed equation; the selection of a set of fundamental quantities, with reference to the system of equations applying to the problem; and the application of the Π-theorem.

The vital question on which the validity of a dimensional analysis rests is: How can we be sure that a relation exists connecting the quantities we have listed, that is independent of the units? How can we be sure that we have not left out some dimensional constant? Bridgman's answer is that the only way we can be sure is to regard the proposed equation as deducible from other equations and ask what quantities enter them. The notion of the system of equations applying to a problem is perhaps somewhat vague but it enters only to the extent of determining what quantities must be included and what units may be taken as independent. A person who has acquired extensive familiarity with problems of a certain kind may be able to settle these questions without writing down a single equation. Thus, while the notion is fundamental to the logic of the method, still the method owes much of its value to the fact that it is applicable to problems of such difficulty that one cannot write down all the equations.

From this point of view, dimensional analysis is not an independent method but a *supplementary* or *simplified version* of the regular analysis. To use Bridgman's phrase, it is an "analysis of an analysis." As such, it would be rigorously applicable only in fields where theory was fairly well developed. In other cases it may give suggestive results and this is one of its most important uses; but unless it can be supplemented with an argument based on the fundamental equations, justifying the choice of quantities and independent units, the result obtained cannot be regarded as *derived* but merely as more or less *probable.*

[7] Riabouchinsky, Nature **95**, 591 (1915).
[8] Reference 1, pp. 9, 72.

NECESSITY is not the mother of invention; knowledge and experiment are its parents. This is clearly seen in the case of many industrial discoveries; high-speed cutting tools were not a necessity which preceded, but an application which followed, the discovery of the properties of tungsten chromium-iron alloys; so, too, the use of titanium in arc lamps and of vanadium in steel were sequels to the industrial preparation of these metals, and not discoveries made by sheer force of necessity.—W. R. WHITNEY.

Lecture Demonstrations in Elementary Physics

N. Henry Black, *Department of Physics, Harvard University*

THE value and the place of lecture demonstrations in instruction has long been debated and probably will continue to be the subject of much discussion. So great a teacher as Alexander Smith abolished the famous demonstration lectures in the general chemistry courses when he came to Columbia as head of the chemistry department and substituted lectures to small groups of about forty men. A few years ago at the Massachusetts Institute of Technology a similar experiment was tried in the physics department. Two years ago Professor Millikan told us that the California Institute of Technology gave no regular demonstration lectures as an integral part of the elementary physics course; in other words, the emphasis was put on the classroom work and the laboratory experiments by the students. Forty years ago, here at Harvard, there were practically no lecture demonstrations before large groups of students. Then Professor Sabine introduced a limited number of illustrated lectures covering special topics which he thought were adapted to this method, and which he himself was interested in presenting, but he gave no connected series of lectures covering the whole subject. When Professor Saunders came to this department, he began giving lectures with demonstrations outlining what he considered to be the main points in elementary physics. Now we give three such elementary courses and in each considerable time is devoted to the lecture demonstrations.

Why do we do these experiments? Because we feel that the experimental point of view must be kept before the student right from the start. Even though theoretical physics is now very popular and attractive to those who have mathematical tastes, yet the theory must ultimately be based on, and tested by, experiments. Another point is this—we find that such demonstrations help to clear up difficult ideas for the student. This is confirmed by the students themselves. We believe that we are saving time by using demonstrations which will reduce the time necessary for oral description. There seems to be little doubt that such demonstrations arouse interest in physics, and sometimes even enthusiasm. It is surely legitimate to add a bit of variety to a dull hour of blackboard work. We trust that we are really making more or less abstract ideas visual and concrete.

How do we go about making these demonstration lectures effective? Here I shall simply give you some of my own personal experiences. Each lecture I try to prepare anew, remembering that the students have never seen or heard of the subject which we are going to discuss. Next, I have learned a great deal by watching good demonstrators and noting some of the devices which they use to make their lectures effective. For example, I find that it is a good practice to prepare the class for an experiment by drawing deliberately on the blackboard a simple but large, clear diagram of the essential parts of the apparatus used. It is my experience that it requires a great deal of planning to keep to one's schedule and to end on time with the subject matter covered. Here I have found great help in reading about the experimental lectures of Michael Faraday, who was surely a prince among lecture demonstrators. In Bence Jones' *Life and Letters of Faraday* there is a sample outline of one of Faraday's well-known lectures, which carefully schedules the topics to be discussed, the time to be allotted to each topic, and the experiments which are to be done. A few minutes before the end of the hour he always had his assistant place a large card in front of him which had printed on it the word "Time," in order to be sure not to run past the hour.

I find that I have a tendency to talk to the people who are near the front, and so I have recently formed the habit of talking directly to those in the rear seats, in order to make sure that my experiments and discussions are heard by everyone.

Finally, I notice that if in the bi-weekly tests I also ask questions on the lecture experiments, there is very much more activity on the part of the students in making sure that they understand them.

What experiments to do? First I may say that we never have experiments simply for the show, or for the astonishment which they produce.

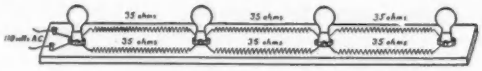

FIG. 1. Parallel lighting circuit with considerable resistance in the line.

Every experiment must illustrate some important principle. Often a crude, home-made piece of apparatus which does illustrate a fundamental principle is more interesting and more effective than some complicated apparatus imported from abroad.

To illustrate, on a long strip of board we have placed four ordinary 25-watt incandescent lamps as shown in Fig. 1. These lamps are connected in parallel, but each connecting wire is high-resistance wire coiled so as to add a considerable resistance in the mains. The result is that the lamp nearest the binding posts shines brightly, the next a little less so, and the last one hardly at all. When asked why these lamps are not equally bright, since they are all in parallel, the students gradually come to the conclusion that there is considerable resistance in the line. Then we try to indicate that there is another factor besides resistance in the line which determines the brightness of the light, and here we measure the voltage at each lamp with a large lecture voltmeter and find that there is a very considerable voltage-drop in the line. Finally we substitute 75-watt lamps for the 25-watt bulbs and note that there is a still greater drop in voltage. Evidently the voltage-drop depends upon both the resistance in the line and the current used.

Another good type of experiment is the one that illustrates unfamiliar notions. Many of our students are already familiar with electrical shunts, but few are acquainted with magnetic shunts. Fig. 2 shows a very simple one-to-one transformer with three parallel iron cores and a yoke that can be slid across the tops of two or three of these cores. When the yoke covers the first two, which have the coils, the lamp on the secondary glows as usual, but when the yoke is pushed across to the third core, then there is a big drop in the brilliancy of the light. This means that the voltage has dropped, because of the fact that a large fraction of the magnetic flux is now passing through the third core—the magnetic shunt.

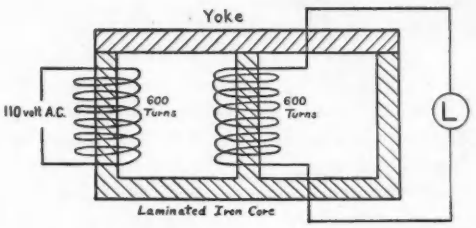

FIG. 2. Transformer with three parallel cores and a sliding yoke.

Another type of experiment which seems justified in these demonstration lectures is the one that shows minute effects. For example, when an ordinary steel rod is magnetized, it expands perhaps 1/400,000 of its length; that is, about as much as when heated 0.5°C. Considerable commercial use has, of course, now been made of this tiny effect—magneto-striction. To demonstrate the effect, I make use of apparatus which I found described in an English physics school book[1] and which we built in our own shops. A 0.5 in. iron bar about 18 in. long, with a coil of wire in the middle, is placed horizontally on a shelf with one end rigidly clamped (Fig. 3). The free end of the iron bar is placed on a small roller. This roller has a light pointer about 1 ft. long which extends below the bench. From the end of this pointer and from another fixed pointer of about the same length is attached a small mirror by two silk threads. A tiny change in the length of the iron bar can be detected by means of the beam of light reflected to the opposite side of the lecture room. That this effect is not due to heating is shown by the fact that the current is on for only a few seconds; also, when the current is gradually increased the effect increases up to a certain point and then begins to decrease, which would not be true if it were due to heating.

Another type of experiment is one in which we have several things happening at the same time that are important to keep in mind. These simultaneous effects are sometimes difficult to portray. Such, for example, is the fundamental principle of the electric generator. Fig. 4 shows a large electromagnet, with a coil of wire between the poles which can be rotated slowly by means of

[1] W. J. R. Calvert. *Physics, Part IV. Magnetism and Electricity*, p. 14.

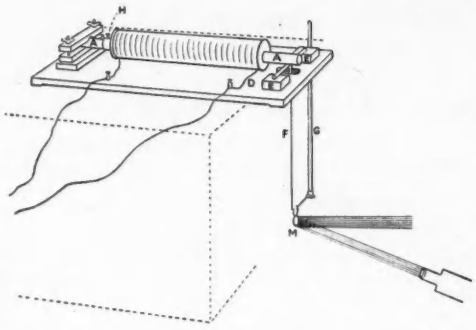

FIG. 3. Magneto-striction apparatus according to Calvert: *A*, iron core, clamped at left end, roller under right end with pointer *F* extending below shelf; *M*, mirror supported by two threads.

a worm gear. The current induced is led off to a lecture galvanometer which is projected on the screen (Fig. 5). The effect when the galvanometer is connected with the slip rings is an alternating current, and when connected with the commutator—a pulsating current; and at the same time one sees the position of the rotating coil for maximum current and for minimum current.

The topics which it seems to me should always be demonstrated if possible are the ones that are really difficult to comprehend, and there are

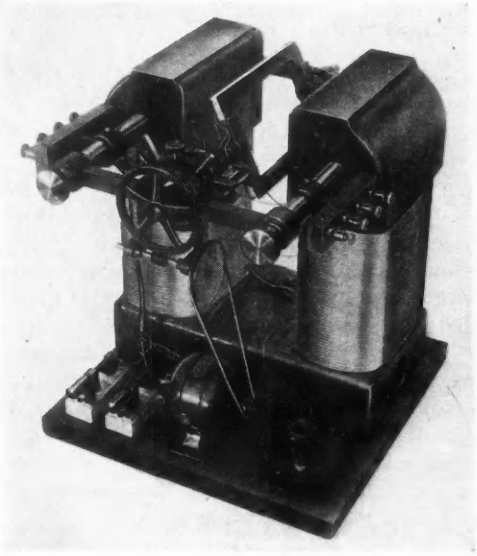

FIG. 4. Model generator.

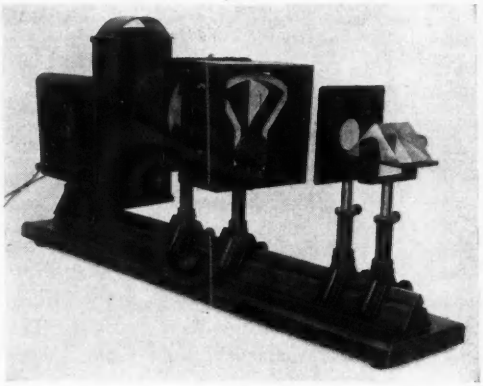

FIG. 5. Lecture galvanometer projected on the screen by means of a 5-amp. arc lamp, a condensing system, a converging lens and an erecting prism.

many such in physics. For example, in the study of alternating currents the relation of the inductance and capacity in a circuit and the condition of resonance are hard to understand. We may draw the vector diagrams on the blackboard and we may derive the algebraic equations for these phenomena, but still the student may fail to get any physical conception. We have therefore found it useful to arrange in series a condenser, a large choke coil with a movable core, and a lamp as an indicator (Fig. 6). When connected to the 110-volt a.c. line the lamp is lighted when the choke coil alone is in series, but is dimmed as we insert the iron core. In the case of the capacity we see that the lamp is lighted when the condensers are connected and that we get more current when more condensers are connected in parallel. Now, when we have both the condensers and choke coil in series with the lamp, we find that as the inductance is increased by inserting the iron core we pass through the point of maximum current. This is of course the condition of resonance.

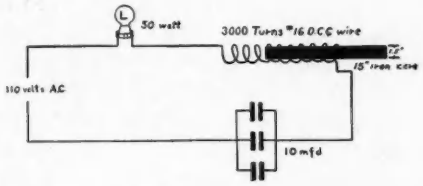

FIG. 6. Choke coil in series with a condenser and a lamp.

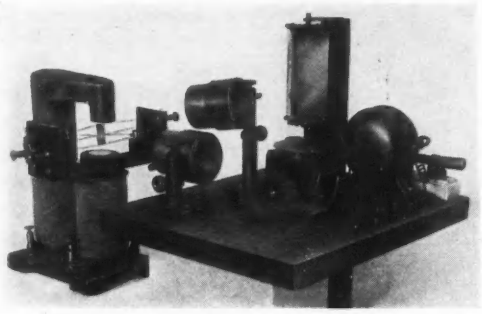

FIG. 7. Simple oscillograph with two plano-cylindrical lenses and a rotating mirror.

Finally, in order to help the student visualize this subject just a little more clearly, we use a simple, rugged type of oscillograph which is made by E. Leybold's Nachfolger in Köln, Germany, but which can easily be constructed in any machine shop. This consists of two hairpin loops of wire in a magnetic field (Fig. 7). In one loop we pass half an ampere of alternating current with suitable resistance from the 110-volt line. In the other loop we also pass a current of half an ampere but insert in the circuit capacity and inductance in series. In order to distinguish these on the wall when projected as sine curves, a bit of colored glass is placed in one beam. Then we can show that when there is no inductance or capacity (or very little), the two currents are in phase; then, as inductance is introduced, the current in one circuit lags behind the other; when capacity is introduced, the current in this circuit leads the other; and when these then are balanced, as in the case of resonance, they are again in phase.

To sum up, let me enumerate a few of the helps which we find almost indispensable in carrying on this work. *First.* A well-equipped shop with tools and materials and men. *Second.* A skillful mechanical assistant who learns how to set up and do the experiments; and when once the right conditions for doing a certain experiment are found, these are written down in a notebook by the assistant and kept. We have thus gradually piled up considerable experimental data. *Third.* A handy store-room with cabinets for keeping the apparatus intact, clean, ready, and accessible. *Fourth.* We have collected a number of books which are of help to us in preparing these lectures. The following list may be useful:

Mecke und Lambertz, *Leitfaden der praktischen Experimentalphysik für Vorlesung und Unterricht*, p. 195, J. Springer, Berlin, 1926.

B. K. Johnson, *Lecture Experiments in Optics*, p. 112, Arnold & Co., London, 1930.

R. W. Pohl (trans. by W. M. Deans), *Physical Principles of Electricity and Magnetism*, 1930; *Physical Principles of Mechanics and Acoustics*, 1932; *Physical Principles of Optics and Heat*, not yet published, Blackie & Son, Glasgow.

A. F. Weinhold, *Physikalische Demonstrationen*, p. 1022, J. A. Barth, Leipzig, 1922.

K. Rosenberg, *Experimentierbuch für den Unterricht in Naturlehre*, vols. 2, pp. 545, 629, G. Freytag, Leipzig, 1929.

Franklin and MacNutt, *A Calendar of Leading Experiments*, Franklin, MacNutt and Charles, South Bethlehem, Pa., 1918. (Out of print.)

W. Volkmann, *Anleitung zu den wichtigsten physikalischen Schulversuchen*, p. 266, R. Muckenberger, Berlin, 1912.

J. Tyndall, *Heat a Mode of Motion; Sound; Lectures on Light*, Longmans, Green & Co., London, 1885.

D. C. Miller, *Science of Musical Sounds*, p. 286, Macmillan, New York, 1916.

W. Bragg, *Concerning the Nature of Things; The World of Sound; Old Trades and New Knowledge; The Universe of Light*, G. Bell & Sons, London, 1933.

E. Grimsehl (trans. by L. A. Woodward), *Textbook of Physics*, vols. 4, Blackie & Son, Glasgow, 1933.

A. Bethencourt, *Cour de Physique*, vols. 4, Librairie Hachette, Paris, 1932.

W. J. R. Calvert, *Physics*, vols. 4, J. Murray, London, 1926.

G. H. J. Adlam (ed.), *The Science Masters' Book, Part I, Physics*, J. Murray, London, 1931.

Duckworth and Harries, *The Laboratory Workshop*, G. Bell & Sons, London, 1933.

Frary, Taylor and Edwards, *Laboratory Glass Blowing*, McGraw-Hill, New York, 1928.

Fifth. I might in addition enumerate miscellaneous aids, such as lanterns for slides, for opaque objects, and for vertical projection. We have a large collection of charts made in colors on ordinary manila board, and models made of wood and metal in large size so that the students can see some of the important parts, say, of the vacuum tube. We have a sensitive galvanometer, a large voltmeter, and an ammeter with illuminated scale conveniently arranged on the wall of the lecture room. Finally, we find that it helps to have the curtains and blackboards arranged so that they will operate from the lecture table by means of switches. But, when all is said and done, the success or failure of demonstration experiments depends not on any of these mechanical aids but on the demonstrator himself.

The Content of the First Year Course in College Physics

A. E. CASWELL, *Department of Physics, Oregon State College*

IN a recent article,[1] Professor F. K. Richtmyer begins by quoting the late Professor Jones, of the Cornell University mathematics department, as follows: "To become a successful teacher of mathematics one must acquire a thorough knowledge of mathematics." The article closes with the further quotation: "and then by constant practice, acquire the art of teaching it." No doubt the impelling motive in the organization of the American Association of Physics Teachers was the desire to improve the art of teaching physics. Upon only one point with regard to this art are we all agreed and that is that college physics is not as well taught as it ought to be. By *college physics* I mean any first-year course offered in college or university whether it be called "general physics," "engineering physics," or what not.

May I first of all propound a few questions? Why is it that during the last thirty or forty years the enrollment in this country in college physics, relative to the total college enrollment, has fallen to one-third of its former value? Why is it that the enrollments in chemistry and in mathematics far exceed that in physics? Why are there so many chemistry and mathematics majors and so few physics majors? Is there less popular interest in the things of physics, and does physics appeal less to the intelligentsia? Does the fault lie in the subject or in the teaching of it?

Which of the natural sciences imposes the most difficult prerequisites? Physics. In which of these sciences are attempts made to offer the greatest variety of courses alleged to be specially adapted to the needs of this, that and the other group of students? Physics. In which science has the subject matter increased the most and the general course changed the least since you and I were students? And again we must answer, physics. Perhaps there is a reason why physics is the most unpopular of sciences, judged by college enrollment.

Throughout the country as a whole, the students who register for college physics are, first, a limited number who have an inherent fondness for the subject and who in all probability will become physics or mathematics majors, and, second, those who are required to take it, such as chemistry, engineering, medical and home economics majors. In times past a large proportion of liberal arts majors elected the course, but now this is true only of a small number of strictly liberal arts colleges, but certainly is not true of the universities and land-grant institutions. For example, a few years ago Alma College had more undergraduate physics majors than the University of Michigan.

I am a firm believer in the propositions that physics is as interesting to the average person as any other science and that it can be so taught as to command the respect and elicit the enrollment of much larger numbers of students than it does at present. That it does possess an attraction for many non-physics and non-technical students is attested by the fact that so many soundly scientific books, such as Bragg's *Concerning the Nature of Things*, or Jeans' *The Universe Around Us*, are so widely read.

As a doctor will you allow me to diagnose the case before prescribing a remedy? You will not agree entirely with my diagnosis. I do not have implicit faith in doctors and so I shall be glad to have you call in others for consultation. In fact that is exactly what I want and why I am discussing this case.

Here are some of the things I find. First, *we have set up too many prerequisites*. Teachers of no other science have set up such barriers. In many cases a course in secondary school physics, two Carnegie units of algebra and a half-unit of plane trigonometry are required for admission to the standard general course. In at least one case that has come to my attention calculus is required for the last term of a course of two lectures and one laboratory period extending over the freshman and sophomore years. In my judgment this is the height of absurdity. My own experience has been restricted to a leading privately-endowed institution, a state university and two land-grant colleges, to the teaching of large numbers of engineers, premedical students, and science majors, and a smaller number of agriculture and other groups. I have yet to find that high school

[1] Richtmyer, Am. Phys. Teacher **1**, 1 (1933).

physics is an indispensable prerequisite. On the other hand, I have repeatedly found that a good student who has never had high school physics will do better work than one who has had such a course. This seems to be due in part at least to the fact that many of those who have had physics in high school think they know it all, and so have developed a sort of immunity. There are professors of chemistry who maintain that the same is true of their subject.

As for the algebra prerequisite, the most difficult problem that one needs to solve in general physics involves a quadratic, and this requires but one and one-half units of high school algebra. As for trigonometry, it would be quite as logical to require proficiency in the use of the slide rule before admitting students to classes in general physics. One can teach a student all of the trigonometry that he really needs to know in about fifteen minutes; after that he will learn to use that little well.

The second thing I find is that *our courses are too mathematical and too problematical.* Indeed we have made a fetish out of mathematics, and the mathematicians should laugh in their sleeves. Physics is difficult to begin with but we have made it more so. The physicist sets up an equation and then he must solve it, and he has become so intent upon the solutions that he has lost sight of the human values. The purpose of problems in our general course is to help clarify physical principles. Yet we have let the solving of problems become an end in itself. It has developed into a cancer within the body of physics. I naturally enjoy the solution of problems, having been originally a mathematics major, who left his first love because he did not want the mechanics of mathematics to become the Alpha and Omega of his existence. So I know how easy and natural it is for us teachers of physics to allow our courses to become mathematics-ridden.

The third thing I find is that *our courses are logical but not psychological.* There are two factors in our teaching problem. The one is the subject matter; the other is the student. Our courses tend to be organized with reference to the former rather than the latter. We have built up courses which in the eyes of the instructor are logical, but it may be that we have forgotten the weightier factor—the psychology of the student. If we baffle and discourage the student, if we make our course a nightmare, we ultimately find we have no students, for somehow the word gets abroad. It will not do to say that we put into the course what is best for the student or that we develop the subject in a logical way. We will get nowhere lecturing to empty seats. It does no good for the doctor to prescribe if the patient refuses to take the medicine. That is why we have sugar-coated pills. If at times we must give the student something bitter, let us sugar-coat it as much as possible. Do not misunderstand me. I am not pleading for a wishy-washy, namby-pamby course, but I do believe that it will pay us to take stock and see what we can do to put physics back into its rightful place on the student's study card.

The fourth thing I find is a matter of stern conviction with me, although I know that many will disagree with me on this point. *We have catered to too many outside interests.* We have tried to please everybody and have pleased nobody. We have meekly submitted to the domination of the technical schools. We have followed the traditions of the elders and our courses are littered with the dead wood and the débris of an earlier day. The result, all too often, is that the course we offer is a replica of that taken by ourselves in our day or by the dean of engineering in his day. The dean may be unaware of the tremendous and significant advances in our field, but we are without excuse. In all fairness it must be admitted that there are many professors of mechanics and other technical subjects who regret the fact that the physics teachers have tried to pluck the bloom from their flowers. I am convinced that it is our peculiar responsibility to teach physics and nothing else. The general course offers the only opportunity that ninety percent of the average class will ever have to study physics. We must make the most of it.

We should draw our illustrations from anywhere and everywhere. Because we are lecturing to a group of premedical students is no justification for drawing the bulk of our illustrations from the field of medicine, or for piling illustration upon illustration and application upon application. That is what the professors of medicine are paid to do. Let us draw our illustrations from every field of human endeavor, remembering to use

those that are already a part of the student's experience in preference to others.

The fifth thing I find amiss is the underlying idea that a course which is best for the physics enthusiast must needs be good for everyone. This is a fallacy. I believe that the converse is true; that is, *the course that is best for the average non-physics student must needs be good for the physics major.*

The sixth and last item in my diagnosis is concerned with the fact that in the long ago, mechanics, with a little simple optics, magnetism, static electricity, heat and sound, constituted the entire subject matter of physics. As the subject has developed we have tried to crowd in some of the new discoveries but have not had the courage to leave out anything that anyone else has kept in. These newer things have been injected into a course that is already too full and so they have been given the attic, while the old and venerable mechanics occupies the front room and gets the first chance at the dining table. Incidentally, may I venture to remark that the old villian in the parlor is not half as attractive in the eyes of the modern student as the young, gay and giddy damsel in the attic who doesn't know where she is going but is certainly on her way.

Now that the diagnosis has been completed I am about to prescribe. However, I wish to reserve the right to change the prescription as experience seems to warrant. Physics is, after all, an experimental science, and to my mind that physicist who goes on teaching his subject year after year in exactly the same way as the fathers did is not worthy of the high calling to which he thinks he has been called.

First, let us determine our objectives. I am reminded of a young man who, when asked by his school superintendent "what he was teaching for" replied instantly, "I am teaching for $35.00 a month." I fear that we are all more or less guilty of teaching physics for our bread and butter. But let us face the matter fairly and squarely. You may discover that your objectives are different from mine but at least we ought to know what it is that we are trying to do. I find that I am not teaching the first course in physics for the purpose of training physicists. Neither am I teaching students how to manipulate physical instruments; that is, I am not teaching techniques. If the students acquire any techniques as by-products—well and good. Neither am I giving a course in the scientific method. I doubt if that can be taught—it must be slowly and painfully acquired. But I am trying to do three things. First, I am trying to give the student a vital acquaintance with the more fundamental and important phenomena of physics. Second, I am trying to make him aware of the physics in the universe in which he lives and moves and has his being. Third, I am trying to teach him to reason from cause to effect, to see visions and dream dreams in the world of physics. I am not so much concerned with whether a student learns to think clearly in all fields but I am greatly concerned that he shall learn to think clearly in our particular field. To this end we have lectures, recitations, questions, problems, exercises of various sorts, and laboratory work.

Second, let us study student psychology. Let us try to see the subject not as an old dried-up instructor sees it but as a beginner sees it. Assume that it is a free elective and that no one has to register for it unless we can make it seem desirable in his eyes. Then go over all the available material carefully to determine the relative values of different topics that are now in the course or may be considered as possibilities. We should do this in the light of the whole of physics as known at the present time. Then, after having studied the interests and experiences of those students who may reasonably be expected to have any interest in the subject, let us select as many of the most valuable topics as can be adequately treated in the time at our disposal. Of course it will simplify matters if one can adopt a textbook in which this process of selection has already been carried out.

I am sure of two things about the completed list of topics. Some of the topics we have always expected to find in the course will be conspicuous by their absence. On the other hand, terms that were unheard of fifty years ago will occur quite frequently and there will also be a certain amount of scientific "romancing," to use a word employed by the *New York Times* in an editorial dealing with cosmic rays. The student will find in this list the things he wants to learn. Those things that deaden student interest will not be there. Or, if they must be included, they will be intro-

duced at such times and in such manners that the students will see the necessity for them; thus their deleterious effects will be diminished.

A couple of years ago a student of architecture, who had married a former student of mine, asked me to outline a course of reading for him. Some of the books which I had given to his wife to read had fired his imagination, but on account of a heavy schedule he could not enroll in any formal class. One of the first books I had him read was Bragg's *Concerning the Nature of Things*. Imagine my surprise when he came to me a short time later with several beautiful crystal models made of colored glass balls cemented together, accurate in every detail and based entirely upon information contained in that simple, non-technical, non-mathematical, non-problematical book.

The appeal that the theory of relativity makes to the average layman is a matter of common knowledge, and there is a considerable amount of the elementary theory that can be made intelligible to the first year student and that will help him to catch the spirit of physics. I believe that, properly presented, many other topics that are usually either omitted altogether or given scant attention would make a similar appeal.

Third, we should seek to appreciate the beginner's difficulties. You didn't swim the first time you tried. There are not many things that you learned to do in one or two trials. We should remember that the student must learn a language, absorb subject matter and develop a point of view. Therefore, definitions should be stated in terms with which the student is familiar and should be free from all ambiguity. The statements of laws should be clear and concise. They should be true regardless of any interpretations that may be put upon the facts. Boyle's law is true regardless of any hypothesis we may hold regarding the behavior of the molecules. We should distinguish clearly between physical laws and mere hypotheses. We should avoid having the student learn words and phrases to be repeated parrot-like. Ideas are the important things; the words are simply the cloaks they are wrapped in.

Since we are not training physicists in this course we should limit the number of units or systems of units to the irreducible minimum. Our problems, questions and exercises should be such as to appeal to the student as worthy of his time and effort, so that when he has solved a problem he shall feel the joy of accomplishment. In how many cases does the solving of problems become the merest drudgery? I plead guilty, I am repentant, and I here and now sign the pledge. In a recent article[2] Professor G. W. Stewart has pointed out that some of the best problems illustrating physical principles are not essentially numerical in their nature.

Laboratory work should not be degraded to mere measuring of lengths, watching of clocks, weighing of objects and reading of thermometers, supplemented by interminable calculations. Experiments should be designed to focus the attention upon the physical principles involved. Many an experiment performed in college laboratories is not worthy of the name and I strongly suspect that it is such so-called experimentation that is bringing the whole of laboratory work into disrepute and is causing administrative officers to wonder whether it is worth all it costs. The laboratory work should be real and vital. When it is, the Carnegie Institution will not need to spend money to determine its value, for everyone will know it as a most valuable adjunct of the classroom instruction.

Let us therefore be instant in season and out of season, trying to find better methods, better selection of subject matter, and better understanding of the needs, the ideals and aspirations to the students to whom it is our duty to minister.

[2] Stewart, Am. Phys. Teacher **1**, 65 (1933).

IT is no paradox to say that in our most theoretical moods we may be nearest to our most practical applications.—A. N. WHITEHEAD.

Pressure Energy—A Misconception

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MANY of the derivations of Bernoulli's theorem which appear in elementary physics textbooks contain two compensating fallacies: they attribute to unit volume of the liquid an amount of energy numerically equal to the pressure, the so-called "pressure energy," in addition to the gravitational and kinetic energies; and they either assert or imply that a chosen portion of liquid has no work done upon it as it passes down a flow tube.[1] The object of this paper is, first, to reveal these fallacies by showing that an incompressible liquid does not possess energy because of its pressure alone, and by pointing out that it is incorrect to ascribe a constant energy to the chosen portion of liquid; second, to give an elementary derivation of the theorem that is free from these objections. E. H. Kennard[2] undertook the same task in a different way several years ago, but without any apparent effect on textbook authors. Furthermore, the writer has found that rather detailed argument has been necessary to convince other physicists on these points. These are the reasons for the extended character of the treatment which follows. Let it be emphasized that we are not here concerned with the energy of compression possessed by a liquid under pressure because of its elasticity; this energy is proportional to the *square* of the pressure, and has nothing to do with the present question. Hence we may best regard the liquid under discussion as *incompressible* as well as non-viscous; a liquid having these two properties will be called *ideal*.

Just as the possession of kinetic energy by a body of liquid signifies that it can do work in being brought to rest, and the possession of gravitational potential energy signifies that it can do work in being lowered to a chosen horizontal reference plane, so would the possession of "pressure energy" mean that the liquid could do an amount of work proportional to its pressure in having that pressure reduced to zero. This amount of work would have to result from the fall of pressure, even when kinetic energy and gravitational energy were absent or remained constant. But one sees immediately that if a rigid cylinder having a piston contains some incompressible liquid, the application of a force to the piston will put the liquid under the corresponding pressure, thus allegedly endowing it with "pressure energy," without the doing of any work on the liquid, since only a vanishingly small displacement of the piston will result. Conversely, as the force is diminished to zero, the pressure and "pressure energy" will vanish, and no work will have been done by the liquid. Thus, there is no meaning for the term "pressure energy" at any stage of this process.

All the arguments used to introduce the idea of "pressure energy" purport to consider the work done by external forces on a volume ΔV of liquid either (1) while it is being introduced into a vessel under pressure or (2) while it is being transported from the surface to a lower point in an open vessel. Uniformly, these arguments ignore the work done by the rest of the liquid on ΔV (or better on the system comprising ΔV and the earth, when gravitational energy is involved); when this is considered, the total work done on ΔV equals the sum of the changes in its kinetic and gravitational potential energies, if the liquid is an ideal one, and there remains no excuse for inventing another form of energy. Careful examination of the arguments mentioned will reveal the fallacy in each.

Next consider a rigid horizontal cylinder which is fitted with a frictionless piston, and to which weightless ideal liquid is supplied by a pump. If outward motion of the piston is opposed, so that the pressure everywhere in the liquid is P, then while a volume ΔV of liquid is being introduced by the pump, an amount of work equal to $P\Delta V$ will be done by the pump piston on the complete

[1] Such derivations are to be found in the elementary textbooks by the following authors: Chant and Burton; Loeb and Adams; Miller; Smith; Spinney; Fitch; Caswell; Knowlton; Little; Millikan, Gale and Edwards; Sheldon, Kent, Paton and Miller; Erikson; Duff; Weld and Palmer; Duncan and Starling; Anderson; Franklin and McNutt. The newer books are indicated first.

Derivations not containing these fallacies are given by: Duff (ed.); Randall, Williams and Colby; Crew; O. M. Stewart.

[2] E. H. Kennard; Science **62**, 244 (1925). He was contradicted by Wm. S. Franklin and also by R. F. Diemel; see Science **62**, 396 (1925). This apparently terminated the controversy.

body of liquid, and the same amount of work will be done on the other piston by the liquid. No energy should be attributed to the liquid itself, which merely acts like a lever connecting the pump piston to the other one.[3] However, the pressure may well be regarded as a measure of the work done per unit volume of liquid introduced, and such is the true rôle of the pressure terms in the equation expressing Bernoulli's theorem, as is brought out in Professor Kennard's proof.[2] We now see that in the type of derivation mentioned at the beginning of this paper, use of the pressure energy concept just compensates for the erroneous assumption that no work is done on the volume element as it passes down the flow tube. This latter assumption is no more justifiable than it would be for a block undergoing acceleration along a frictionless horizontal plane.

Keeping this in mind, one can derive Bernoulli's theorem correctly as follows.[4]

Consider any two points, A and B (Fig. 1) of a particular flow tube, and let h_A and h_B be their respective heights above an arbitrarily-chosen reference plane. Let P_A, P_B, v_A, v_B represent the pressures and speeds, respectively, at the two points, and ρ, g the (constant) density and acceleration of gravity. We fix our attention upon that portion L of the ideal liquid which, at some chosen instant, occupies the section of the flow tube between A and B, and follow it while its forward end moves a short distance to B', its other end to A'. A *correct* formulation of the law of the conservation of energy for this case is:

Work done by surrounding fluid on L
= Increase in gravitational potential energy of L
+Increase in kinetic energy of L;

or,

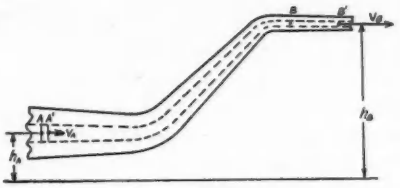

FIG. 1. Derivation of Bernoulli's theorem.

$$P_A\Delta V - P_B\Delta V = \rho\Delta V g h_B - \rho\Delta V g h_A + \rho\Delta V v_B^2/2 - \rho\Delta V v_A^2/2, \quad (1)$$

where ΔV represents the equal volumes of the two regions, AA' and BB'. The two terms in the left-hand member of Eq. (1) give the work done on L by the fluid following it and the fluid preceding it, respectively. To get the first pair of terms in the right-hand member, we notice that the potential energy of that part of L which occupies the region $A'B$ in the second configuration is the same as that of the other part of L which occupied $A'B$ in the first one, so that the net change is given by subtracting the loss due to vacating AA' from the gain due to occupying BB'; the last pair of terms is obtained in exactly the same way, considering now kinetic instead of potential energy. The differences in pressure and speed between the neighboring points of the pairs A, A' and B, B' are neglected. From this equation, one obtains immediately that

$$P + \rho gh + \rho v^2/2 = const. \quad (2)$$

for all points of a single flow tube, which is Bernoulli's theorem.

Some insight into the reason for the persistence —and usefulness—of the "pressure energy" concept may be gained by reflecting that when such a term is added to the kinetic and gravitational energy terms, the result gives the total work which will be available per unit volume of liquid *when it emerges* from the section of flow tube. The fallacy lies in crediting each particular unit volume with that much energy *before emergence*, for the term in question represents work which will be done on it by the liquid behind *as it emerges*. One hesitates to oppose an idea that has a certain usefulness, but when a treatment is definitely wrong, and so easily leads to wrong results and wrong physical conceptions, there seems to be ample excuse for suggesting its avoidance.

[3] It may be argued that the total "pressure energy" of the liquid represents the total amount of work which has been done on the first-mentioned piston, and thus is a measure of the energy communicated to the mechanism which opposes its motion. But unless the opposing force is constant throughout the motion, the total "pressure energy" at the end is *not* equal to the total work done; if, for instance, this force is an elastic one, the average value of the resisting force will be only half its final value, and the total "pressure energy" *twice* the total work done.

[4] For this derivation, the writer is indebted to his colleague, Professor J. Rud Nielsen. Of the elementary derivations found in books, most of those which are not open to the "pressure energy" objection fail to keep a particular portion of the liquid under consideration throughout.

Physics in Relation to Medicine. (Continued)*

IV. Course in General Physics

Preparation in physics for medicine being usually limited to one course, the committee has necessarily made it a subject of careful investigation.

1. *Purpose.* The extended field of physics and of its application to medicine renders it impossible in a single course of reasonable proportions to convey even an elementary grasp of the principles, familiarity with all the most important physical phenomena, and practice in the technique of their application to medical instruments. At which should one aim? Shall one try by many lectures, illustrated by experiment and by lantern slides, to leave the student with a picture of the multitude of beautiful and interesting phenomena, and particularly those obviously applicable to medicine, and to store his mind with rules and formulas for applying them? Shall we teach him to take x-ray photographs, to use a refractometer and a polarimeter efficiently, and the technique of the sphygmomanometer and the hydrogen electrode? The student himself will think our course practical and interesting and apply himself to it more if we do all these things, and for that reason the illustrated lectures at least have their place. But, as already stated earlier in this report, the essential purpose of the course is to give a *grasp of principles*, the structure of the science as a connected whole, and particularly those concepts and laws which underlie all the physical sciences. The importance of this or that physical phenomenon or instrument will wax and wane; will depend on the future career of the student, and change with the development of medicine. But he who really grasps and can use such concepts as acceleration, force, mass, momentum, temperature, pressure, electric charge, current; who has a clear idea of energy and its conservation and can apply it correctly to work and heat changes, to electrical potential, and to the phenomena of the electric circuit; to whom the kinetic theory of matter is real and vivid; and who understands such special topics as elasticity, periodic motion, and waves: that man has the essential foundation for a structure that will grow as he grows. Fortunately most of those of whom we sought advice agree to this. The committee was particularly impressed by the fact that medical school authorities were more emphatic than were the physicists we consulted in recommending for medical students a *good, stiff, systematic*, and general course, similar to that recommended in Report Number 1 for students of engineering,[1] and not one emasculated for a supposedly unmathematical brain. For example, our replies from physicists lay much less stress than do those relating to students of engineering upon adequate mathematical preparation and on numerical problems. The medical authorities do not seem to desire this distinction carried as far as it seems to be. Teachers of medicine regard physics as the main opportunity for training in that clear and precise thinking which is necessary before a scientific problem can be stated in numbers. They seem to value this aspect of the study as a corrective for that very aversion to mathematics which the physics teacher notices and which inclines him to more qualitative methods. The committee may, therefore, once more repeat that the main purpose of this course is a systematic and fairly rigorous development of the fundamental principles and concepts of the science as a whole, together with abundant reference to phenomena and applications, but as illustrations rather than for their own sake. *The student must be left in a position to extend his knowledge with reasonable confidence and success by his own efforts as his future interests develop.*

2. *Time Required.* Great diversity was shown in the replies as to the actual time devoted to the study, and its distribution. Nevertheless the committee is able to fix with confidence the minimum total time required for the accomplishment of the purposes outlined above. This has been done by comparing the time now devoted to the typical courses studied and the

* Concluding sections, IV to VI, in this issue. Sections I to III appeared in the May issue.

[1] Report on Engineering Physics, published by the American Physical Society.

suggestions and criticisms of the instructors, with time allowed engineering students for a like course. Admitting that the latter apply physics more constantly in their profession, the engineering studies themselves afford a constant review and amplification of the fundamental knowledge derived in the physics course. It would also be easier to name fields of physics that the engineer does not "need in his business" than to make similar exclusions for medicine. Noting what has actually been accomplished in the first course in physics by engineering students, the general complaint of inadequate time for that course, and the fact that those students are undoubtedly more apt in physics than the premedical ones, we cannot consider courses which allow the latter only half the time allotted to the former as satisfactory.

We, therefore, suggest, as the minimum, 8 or 9 percent of an average four-year college education. That is, if given in one academic year of some 30 weeks, the study should count about one-third of the work for that period, or approximately 12 semester hours. In other words, we estimate that the average premedical student will take at least 500 hours, including home study and reading as well as instruction, to attain such a grounding in the science as is absolutely necessary, if he is to apply and extend his knowledge by himself. If less is given, the course will either be robbed of interest by scanting the presentation of phenomena and applications, or the unity of the science will suffer and it will fall into disconnected topics; or the definiteness of the instruction will suffer by curtailment of laboratory work or of numerical problems.

3. *Distribution of Time by Subjects.* We can recommend as good practice that about one-third of the total time be devoted to mechanics and properties of matter; one-third to electricity; one-third to heat, wave-motion, sound, and light. There is a tendency, which is apparently correct, to devote rather more time to the third subdivision than to either of the other two, but this should not be carried too far. In all parts of the subject some attention should be devoted to recent advances in physics.

4. *Distribution of Time among Classwork, Laboratory Work and Home Study.* The total time has purposely been stated as generally as possible in order to give the instructor a fair opportunity, but allow the greatest freedom in the manner in which it is used. A subdivision in accord with existing practice in most institutions would be three to four hours per week of lecture and recitation, one three-hour period for laboratory work, and a second like period to be used either for more laboratory work, problems, or conferences, as the progress of the course suggests. This would leave six or seven hours per week for study and reading, which is none too much. For the superior student it would be highly desirable to increase the time devoted to reading and study, and lessen that for class instruction. A single illustrative lecture and one laboratory period a week with an hour of private conference with an instructor would, perhaps, be the irreducible minimum even for the best students. It is understood that such men should devote at least ten or twelve hours a week to reading.

A contrast to the schedule suggested is afforded by the course at the University of Chicago—one lecture and four two-hour laboratory periods weekly for 33 weeks. The actual teaching takes place almost entirely in the laboratory periods, which are really conferences between instructor and students in small groups, and combine all the elements of recitation and problem work as well as experimentation. Well carried out, as it appears to be, the plan is admirable. It affords freedom and flexibility to adapt the teaching to the individual and the most favorable opportunity to make clear what is not understood. The difficulty would seem to lie in securing adequate instructors and sufficient space.

5. *Formulation of the Requirement.* In default of a better method the medical schools must probably continue to state their requirement in hours devoted to the subject in college, and specify their distribution between class and laboratory. The requirement should not be administered in a book-keeping spirit, but should be regarded merely as a rough measure of the extent of training desired and the relative weight attached to theory and experiment. It would be better, in estimating the merit of individual courses, to compare the time included and the

textbook used. A rapid inspection of the laboratory note-book will serve as a guide to the quality of the applicant and the standard of the instructor. An entirely unfamiliar course might be referred to the department of physics. In any case the course should be accepted or rejected as a whole unless there is a clear inadequacy in some principal subdivision; for example, no light or sound, or no electricity. The committee sought for suggestions for stating the requirements otherwise than by hours of instruction. Only one was received—an examination set by a committee of physicists and medical men.

6. *Separate Instruction for Premedical Students.* In many institutions students in general physics are divided into engineering and academic groups, to which entirely different courses are given, and sometimes again according as they have or have not had physics in school. A further subdivision by which premedical students might be given a special course is not regarded as feasible. The committee accepts this as sound policy, particularly in view of the movement to secure special consideration and more rapid progress for the superior student. One of our correspondents was very eager for a separate course for premedical students, but the general opinion was that little differentiation would be possible in any event, except as to illustrative material or in choice of laboratory experiments. The time available does not get us to the parting of the ways. A section of the ablest students from all categories would seem much more desirable for its broadening effects, more rapid progress, and the substitution in part of reading for textbook study and formal instruction, and this would allow much greater freedom in the adaptation of the work to the interest of each student.

On the other hand, it is highly important that teachers of physics who have many premedical students should familiarize themselves with the applications of physics to medicine and biophysics, draw on the material extensively for illustrations, and provide copious references for those willing to read. This will help to open the eyes of the student interested in medicine to the importance of physics to him and thus enlist his interest, whether or not his predilection for medical topics is as developed at that stage as some educators believe.

7. *Prerequisites and Arrangement of Courses.* The fundamental purpose of the course, as has been stated, is to prepare the student to apply the science and to extend his knowledge by himself. It is difficult to do this if his training in mathematics has not been adequate. The course here recommended would come in the second year of college work, and should be preceded by a year of college mathematics, planned so as to meet the needs of the science student. In the course in mathematics, as well as in that in physics, students should be taught to regard equations as statements about physical things, rather than as mere relations between numbers. An increase in the amount of mathematics would not, in itself, meet this requirement. The emphasis needs to be laid on the nature and quality of the work.

This sequence of courses might be difficult in a two-year premedical course. Some sacrifice of standards in every respect then becomes necessary. It is highly desirable that students who are to take physics in the first year should enter with some knowledge of trigonometry, logarithms and the elements of coordinate geometry. If a student has neither studied trigonometry in school nor been able to acquire, by outside study, the very elementary knowledge of it that is needed in the study of physics, the teacher of that subject is compelled to resort to one of several disadvantageous expedients. He may stop to explain the elementary trigonometrical terms as he needs them, or arrange with the mathematics teacher to do so as early as possible, and take up light, which requires the least mathematics, first, instead of following the usual order. In any case he sacrifices time and efficiency in the presentation of his own subject.

8. *Lectures, Recitations, Conferences.* The committee refers to Report Number 1 on Engineering Physics, for a detailed discussion of teaching methods in the general course. We may mention briefly a few important points and note some differences in our replies and those to the engineering questionnaire.

The committee calls attention to that part of Report Number 1 which emphasizes the importance of good

experimental lectures as a means of interesting the students. Without such the course becomes dry and abstract. As a means of instruction, however, our replies attach, perhaps, less importance to them than to work in sections, placing their chief reliance on work in the latter. For a section, 25 students is an undesirable maximum, 15 or 20 being preferable. In this respect and also as regards the general conduct of the recitation, we are in agreement with teachers in engineering colleges (Report 1, p. 19). But even larger recitation sections are a smaller evil than requiring the same instructor to teach several sections. Thirteen to fifteen hours of instruction, with the attendant correction of exercises and handling of apparatus, should be the limit for each teacher. Lessons on assigned topics are not thought advisable, but frequent short written tests should be given, and the remainder of the time should be devoted to conferences, that is, to discussion intended to bring out difficulties, to the suggestion of points of view not in the text, and to working problems.

An occasional lecture at the usual hours ought to be given by some one other than the regular instructors. For example, at Chicago, Professor Michelson talks on elasticity and interference, A. P. Matthews, a physiologist, on capillarity as applied to biology, and at Johns Hopkins, Professor Wood on the liquefaction of gases. This stimulates the class and gives them a glimpse of a level that cannot be maintained in the regular routine. It differs from the sporadic lecture, open to the student body, by being specially to the class and by the possibility of better coordination with its progress.

9. *Laboratory Work.* No part of instruction in physics has been more criticized than the laboratory work. It is said to lack the spirit of experimentation, to be nothing but a training in technique, to be hopelessly uninspiring and dull, and to fail to take advantage of the natural interest of the student in physical phenomena and apparatus. The fact is that our laboratory work is the offspring of "Physical Measurements" and it is possible that it takes too much after its dam. This committee finds that laboratory teachers would like to do the things they are criticized for not doing, but that there are usually difficulties in the way of any radical change in the type of laboratory instruction, and also that the first course in physical laboratory work is looked to for a certain very definite training in methods and instruments. The problem of the laboratory course, as of the rest of elementary instruction in physics, is to do the best with a certain limited amount of time and money. The laboratory teacher tries to use these to increase the student's knowledge of physical laws and phenomena and to help him to a more definite and concrete idea of them, and, secondly, to fulfill in some measure the expectations of other departments as to training in technique. On the whole our correspondents feel that they are meeting with a certain measure of success in reaching these limited objectives, and that the development of the research attitude must be postponed to later and smaller courses. Professor Richtmyer describes a very interesting second laboratory course in which the student is assigned some definite substance and given the problem of determining a great many of its physical properties, density, refractivity, conductivity, and so on, selecting his own methods. Given to only a few students, it is highly successful, but he points out the hopelessness of applying such methods to classes of several hundred.

On the whole the happiest suggestion for such classes is due to Professor Farwell. Outline a definite piece of work to be done with definite equipment, but make the directions brief, so as to leave details to the student's ingenuity. If the man finishes before the end of the period, encourage him to try further experiments of his own, without requiring him to submit notes. It must be understood that in any case every student remains in the laboratory for the entire period and makes the best use he can of his time. The system of marking should be such as to encourage quality, intelligence and comprehension of the problem, rather than quantity.

The interest of the student depends mainly on the selection of the experiments and on the right sort of standard as regards numerical results and accuracy. He generally likes to use a good instrument, which gives data that appeal to him as reliable, and he likes to get a good result. He is discouraged by the reverse and his fickle interest is lost. The moral is to furnish good equipment, though care must be taken that it is not the elaborate kind that conceals the principle and eliminates skill. The best labor-saving instruments of research laboratories would often be the worst for teaching. The student does not like work of which the obvious purpose is to learn how to use some instrument, and technique must be largely a by-product, acquired unconsciously with a more interesting goal in view. This requires all the more watchfulness on the

part of the instructor to prevent incorrect and careless habits. In short, while the instructor ought to distinguish between intelligent work and a good result, he ought not let his students get the idea that the result makes no difference.

What has been said applies to quantitative experiments, which the replies of the committee indicate to be the most common type, and very properly so, since the object is to do illustrative experiments on laws and relations of physics which are mainly quantitative. Some purely qualitative experiments are given, and also others in which the observations are numerical but cover a variety of rapid tests rather than a single more accurate determination, for example, in comparing the same physical property, such as specific heat or resistivity, in several substances. The committee would like to see this type of experiment more frequent, and also the custom of bringing apparatus commonly shown in lectures into the laboratory and letting the students handle it.

The committee was glad to find that most of its correspondents felt that the main duty of the instructor in the laboratory is to draw out the student's knowledge of physics and of the work in hand, and to judge his merits on the spot and not on the basis of a written report. He is not there simply to help the student adjust apparatus and get data. It is evident, however, that we tend to slip into the second attitude, and to keep us teaching physics and to secure the proper emphasis on the student's work in the laboratory require effort and safeguards, one of which might be the abolishment of the report written at home. Most of the engineering replies and some of ours, however, regard the written report as valuable for the sake of the student, though the issue is not clearly met whether the report is worth more than an equal amount of time spent in preparation for the experiment beforehand, or in reading. But we know when we get the report, and perhaps if we abandon it we may not be sure whether we get the equivalent.

Our replies and the engineering ones agree that 12 or 15 students to an instructor in the laboratory, or one instructor and an assistant to 25 is good practice. Sections of 20 to 25 students per instructor are common, but are considered too large.

With the small section a laboratory examination is needless, for the larger ones it is desirable, a practical test being preferable. At Johns Hopkins a practical test at the end of the year used to be required of all students with laboratory grades below 85. Each student spent 45 minutes with each of four examiners, who set some simple task, saw how he went to work, and asked a few questions. Even with eight or ten students in the room at a time, it was easy to gauge their qualifications, and the test was highly successful and valuable. But it was found so laborious that, with increasing classes, a three-hour written examination has been substituted, distinct from the class examination. This seems to be decidedly worth while.

10. *Problems.* This part of the work is looked upon as of the highest importance in the engineering replies, and in most of ours, though some report that they have no time for it. It is agreed that not much reliance can be placed on problems done at home and handed in. The approved method is to require this as part of the student's preparation, but to base grades on work done in class only. The instructor should work problems himself to show how they are done and call on members of the class to do others, and all should be discussed by the section. This is conceded to be the best way to teach, but it is terribly time-consuming, and the fact that it is regarded as necessary points again to lack of responsibility and purpose on the part of the college student as a source of inefficiency.

V. Elective Course in Physics for Premedical Students

In Part III of this report the committee has recommended that, in addition to the course in general physics required of all premedical students, there should be a suitable elective course, to be taken only by such as have time for it, and ordinarily in the third or fourth year of college. This has not been so fully studied as the general course, and its exact character and content must depend largely on the resources and personnel of the institution offering it. It should consist largely of laboratory work, which it would be comparatively easy to adapt to the special needs of students going into medicine.

Whether it would be possible to give a lecture course specially for them would depend on the resources of the department and the demand. It ought to be possible to plan a reading course, at least, or a course of lectures suitable for advanced men in biology and chemistry as well as those specially interested in medicine, for example, on radiology, including heat, light, x-rays, and radioactivity: or, as suggested by Professor Richtmyer, "Radiation and Life." It ought to be a thorough treatment of a limited field rather than an attempt to cover general physics over again.

In the laboratory the aim should be to teach the correct use of physical instruments and methods specially applicable to medical problems. More stress should be laid on precision than in the first course and the apparatus should be of a standard type used in research rather than the simple form advised for elementary students. It may be assumed that the student also studies physical chemistry and the work should not duplicate measurements likely to be taught in that course, such as boiling and melting points, work with an analytical balance, conductivity and hydrogen electrode determinations. Perhaps it would be desirable that chemists and physical chemists should be more familiar with the physical principles and sources of error in their measurements, but the remedy is clearly in closer relations between the departments, rather than in duplication of the work. Omitting these one might suggest some of the following:

EXPERIMENTS SUGGESTED FOR ADVANCED ELECTIVE COURSE

Mechanics

1. Density and specific gravity.
2. Manometers; sphygmomanometer and sphygmograph and their calibration.
3. Viscosity; viscosity determinations based on flow through tubes, and by rotating cylinder or disk.
4. Surface tension.
5. Measurement of long and short time-intervals.
6. Production and measurement of low pressures.

Heat

7. Thermometers, including study of lag and stem correction.
8. Resistance and thermocouple thermometry.
9. Study of heat conduction and loss, and insulation.
10. Regulation of constant temperature baths and ovens.
11. Principles of calorimetry.

Light

12. Refraction; spectrometer and refractometer.
13. Microscope and reading telescope.
14. Spectroscope, spectrograph and spectrophotometer.
15. Colorimetry.
16. Photometry.
17. Polarimetry.
18. Radiation and measurement of wave-length and of radiant energy.

Sound

19. Production and measurement of tone, pitch and intensity.

Electricity

20. Measurement of resistance by d.c. and a.c. methods.
21. Measurement of current, direct and alternating.
22. Measurement of voltage, direct and alternating.
23. Galvanometers and their applications.
24. Cardiography with the string galvanometer.
25. Vacuum tubes and their use as amplifiers and as oscillators.
26. Instruments used in radioactivity measurements.
27. X-ray technique.

In order to make his teaching more effective, the instructor in this course should keep in mind that for this particular group of students physics is only the means to an end. He should, therefore, endeavor to make the course as practical and concrete as possible without sacrificing the teaching of fundamentals. He should consult freely with those members of the medical faculty who are doing experimental research in order to obtain an insight into the physics of their problems.

Training in the Judicious Use of Instruments and Data. More than ever before is the modern medical man dependent upon laboratory instruments and data. Should he by chance enter the research field, his real success is likely to be almost entirely due to his knowledge of his apparatus and as to what his results are quantitatively worth. The Committee believes that an adequate training in physics will include a sufficient emphasis upon the theory of measurements. While most laboratory courses give some attention to measures of accuracy, it is frequently perfunctory only, and often considered only in connection with so-called "precision" experiments. As a matter of fact, it is extremely important that the man who is able to secure only an inaccurate result, should know enough not to attach undue importance to it. The field of medicine, by its very nature, affords many

corners where even the best observers can see but dimly.

If the treatment of measurements is made practical, with consideration for the proper use of slide rules, seven place logarithm tables, graphical methods, etc., it need not take on a wholly dry-as-dust appearance. There are suitable texts covering this phase of the subject, some of which merit a more general consideration than they have yet received.

VI. Summary

The committee has called attention to the greatly increased importance of physics in relation to medicine, to the realization of this by medical men, and to the desire on their part for increased cooperation of physicists in medical research, and for better preparation in physics for the study of medicine. They have made the following recommendations, presenting the reasons which have governed them as fully as possible without unduly extending the length of this report:

First: That successful participation of physicists in medical research can best be secured by the appointment of one or more physicists on the staff of medical institutions. The duties of such men should include cooperation in research, advice in the application of physical methods and instruments in medical practice, and systematic instruction in one or more courses open to students or any other members of the institution who may desire it.

Second: As regards education in physics preparatory to medicine, they feel that in view of the other great demands on the time of the student, the amount of physics required of the average student for entrance to the medical school should be limited to one good course of general physics in college, but they urgently recommend that this course fulfill the following conditions as essential to the accomplishment of its purpose:

a. The course should aim to instil the fundamental principles and concepts of the science as a whole, and the ability to apply them, rather than to teach particular phenomena or methods, supposed to be appropriate to present medical practice. The student must be left in a position to extend his knowledge by his own efforts in accordance with the future development of his interests and the progress of medicine.

b. The course should, if possible, come in the second college year and be preceded by a year of college mathematics. This amount of preparation in mathematics is not excessive in view of the importance of physics to the medical student and the fact that physical chemistry, which requires a considerable use of mathematics, is also usually required for the medical school.

c. If a year of college mathematics cannot possibly precede the course in college physics, a good working knowledge of elementary trigonometry and logarithms should still be considered as an important prerequisite. It should, therefore, so far as practicable, be required for entrance, if the course in physics is to come in the freshman year.

d. The committee estimates that to accomplish its purpose a total of at least 500 hours of the student's time will be required for the course, including class work, laboratory work, home study, and reading, and the minimum time and credit to be assigned to it in the curriculum should be 12 semester hours.

Third: In addition to the required course in general physics, an elective course should be provided, suitable for students who desire more knowledge of physics than the general course affords, but who expect to apply their knowledge to medicine or biology, rather than to engineering or physics. The additional training afforded by this course might be recognized by the medical school by accepting it from a limited number of students in lieu of some other requirement, for example, in lieu of a second year of biology. It should normally be taken in the last year of the college course, and be looked upon as an advantage accruing from a four-year preparatory course and usually out of the question in one of two years only.

Fourth: There should be provision in the medical school for one or more courses in biophysics, or physics applied to medicine, as electives, usually to be taken in the last years of the medical school course, after the student knows enough medicine to realize the importance of the subject, and has some idea of the field to which he intends to apply his knowledge, so that the course can be adapted to it.

Charts

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THE chief function of charts is to serve as the source from which the student copies his lecture notes. In this function they are supreme. Physics cannot be learned thoroughly merely by reading the textbook, or by listening to the instructor, or by watching classroom demonstrations, or by reciting in the brief oral manner which limited time permits. These have their places but to be thorough, the student must *use his hands* in the learning process: he must work in the laboratory, solve problems, *write out* all of the important definitions and derivations, and *draw* the diagrams.

The average student cannot be depended upon to make a real effort at understanding material that he is required to copy into his notes directly from the textbook, mimeographed material, or library references. Such copying is regarded by the student as "made-work," to be done mechanically if he cannot afford to have some one else do it for him. The only effective note taking is that done in class from material explained in class. This material should be clear and forceful in its organization and it should command attention by its beauty. Moreover, it should remain in sight long enough to be copied under normal conditions, with access to it after class being possible if necessary. Oral dictation obviously is not the answer. Work hastily thrown onto the blackboard during the course of the lecture is notorious for its lack of clearness and beauty, for unconscious errors, and for the offense of being erased before all of the students have finished copying it; so the miserable blackboard drawings and cuneiform chirography of the typical lecturer are not the answer. When the lantern is used, the room is darkened and the ventilation is impaired; the lantern is not the answer for effective note taking.

If anyone doubts that *good* charts *are* the answer, let him prepare for himself enough really fine charts to make a thorough test, and then note their effect on several classes. He will be satisfied. Observe that the charts must be *explained* in close conjunction with the student's act of copying them into his notes. They must be brief, for they are to serve merely as an outline which covers only the most essential points. They must be amplified both by word of mouth, and by showing upon the blackboard the stages of development of the derivations and drawings summarized upon them. Problems, recitation, demonstration and laboratory have their usual places in the class routine when using charts.

KINDS OF CHARTS

Four classes of charts will be described in this paper. These are: (1) blackboard drawings prepared before the lecture, (2) drawings preserved for a longer time on portable blackboards, (3) charts on cardboard and (4) charts on cloth.

Blackboard drawings prepared before the lecture usually are limited to exceptionally difficult or important subject matter. White chalk should be used for most of the chart, colored chalk being reserved for distinction and emphasis. A recommended supply of the latter is: 1 box of assorted colors, and 1 box each of yellow, pink or very light red, very light green, and very light blue. When dark colors are used on the blackboard, they must be outlined with white. The author also makes extensive use of colored chalk during lectures for which he does not have charts. In this case one should refrain from touching the face or clothes with the hands and should have easy access to soap and water.

The second stage, the use of *portable blackboards*, permits a longer retention of the charted material; the charts may be referred to on more than one day and students may come in after hours to copy a chart that they have missed in their notes. One should have from six to twelve portable blackboards. A good blackboard can be made from wall board, 4 ft. square and 1/4 in. thick, which has been coated on both sides with blackboard paint and framed as shown in Fig. 1. If most of the material that one wishes to have included in the students' notes is charted, from two to four charts will be needed for a lecture period. Inasmuch as it takes from one-half hour to an hour to make an attractively finished 4-ft. chart, considerable time is needed for this preparation. Nevertheless, if sufficient time is devoted to the making of these temporary charts, the later preparation of permanent charts will be

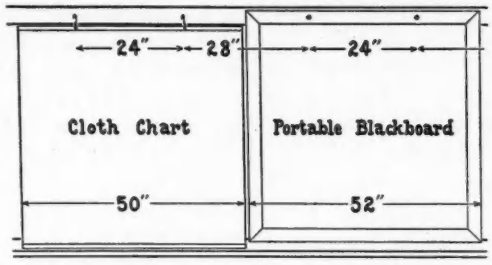

FIG. 1. Cloth chart and framed portable blackboard displayed in front of the ordinary blackboard.

along maturely chosen and well-tested lines of development and subject matter.

The third stage, *charts on cardboard*, is semi-permanent. For quick preparation it will suffice to use ordinary colored wax crayons or the larger wax crayons used to mark freight for shipment. For elegance one should use sign writers' colored inks and pens. In the latter case, the drawing and lettering should be put on the chart in pencil and then traced free-hand with the pen.[1] Inexpensive cardboard, 24×36 in., of a somewhat yellowish color, can be obtained from print shops. White cardboard, 28×44 in., is recommended for the better charts.

The top and bottom edges of cardboard charts may be kept from breaking by gluing to them strips of cardboard or cloth, although the warping tendency in this case is objectionable. Another method is to use strips of wood, 1/4 × 1 in., in the edges of which are cut slots for the insertion of the chart edges; the chart is held in the slots by glue and by brads. Loops of string glued to the top of the chart, 1/4-in. holes in the top strip, or finishing nails in the end of this strip, serve to suspend the chart from nails. Wooden clothespins of the snap type, may also be employed to hold the charts; the jaws grip the cardboard edge firmly without tearing it, even when the edge is not reenforced. Two holes are bored in an arm of the clothespin, a short piece of iron wire is fastened through them and its free ends are twisted into a hook for hanging the clothespin from a nail, or from a wire stretched across the room. Cardboard charts may be stored by stacking them in piles under wooden covers.

The final stage of charts, the use of *cloth*,[2] should not be attempted until something worth making permanent has been worked out. Remember that the combination of simplicity and elegance in the composition of the chart is of the utmost importance in determining its instructional value. In planning the chart, draw it several times on a portable blackboard, testing each trial in actual class instruction, and then make a final model on a blackboard or paper of the same size as the proposed cloth chart.

A drawing board for cloth charts should be made on the pattern of the portable blackboard (Fig. 1), except that one face of the wall board is to be flush with the face of the wooden frame. The frame should be accurately square and rigid. The chart is fastened to the drawing board with thumb tacks. The drawing and lettering are made on the finished face of the cloth with a hard pencil, and with the aid of a large *T*-square made of well-seasoned maple wood and having an 18-in. cross-piece and a 50-in. leg.

When inking over the pencil lines the chart must be practically flat. For this purpose it is best to transfer the chart to another 48-in. square slab of thick wall board laid flat upon a small table, so that one may be able to stand close to any of the four sides. Use sign writers' pens. Press the point lightly, flat against the cloth and pull the pen in the direction of its holder. Dip the pen directly into the ink but shake off a little of the ink by tapping the pen lightly against the neck of the bottle. Do not use a ruler when inking straight lines but follow the pencil mark free-hand; minor imperfections will not show at a distance. Satisfactory widths for the inked lines are 1/16, 1/8, and 3/16 in., the first being used the most. Corresponding to these widths are the Esterbrook Drawlet Pens, Nos. 3, 4 and 5, or the Speedball Pens, Nos. B-2, B-1 and B-0. These pens have rounded points, which are the easiest to use. The three different sizes of pens, with holders, should be provided for each color of ink. A brush should be used for the white ink that is used to cover up errors. A high grade of waterproof ink should be used.[3] Suitable colors are black, brown, red (carmine), orange, green,

[1] The selection and use of pens and inks are discussed in connection with cloth signs.

[2] The ordinary 36-in. width of white sign cloth imposes too great a limitation on freedom of composition. Use, instead, the 48-in. width; for example, White Banner Sign Cloth, Style 70, 48 in. wide (actual width, 50 in.), $14.00 per 60-yd. roll, Bert L. Daily, Inc., 126–130 E. Third St., Dayton, Ohio. The charts should be cut square.

[3] For example, Higgins' Waterproof Drawing Inks, price 25 cts. per 3/4 oz. bottle. Black and orange are used so much that the 1/2 pt. bottle, costing $2.00, is more economical. Charts left for five years on the wall of a room, where they were exposed to occasional sunlight, chemical fumes and wind-whipping, are still quite clear although a little faded in color.

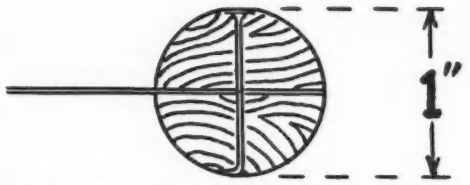

FIG. 2. Method of attaching strips to edge of cloth chart.

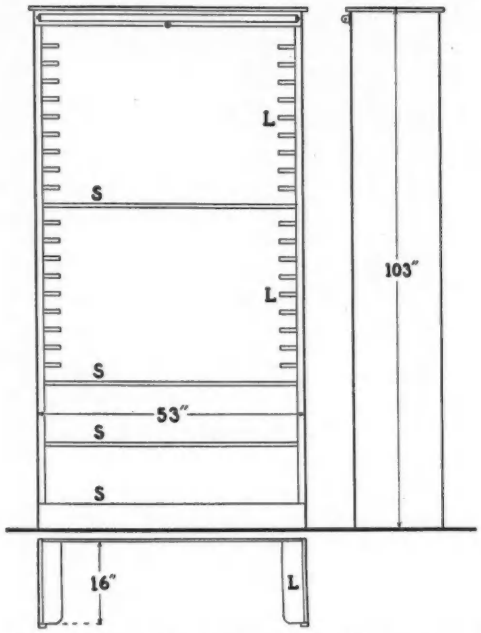

FIG. 3. Front and side elevations and cross section of storage cabinet. The stored charts span the space across the cabinet between the ledges *L*. The shelves *S* may be used for books, etc. A roller curtain pulls down from the top to protect the charts from dust.

blue, and violet. The orange should be mixed with a very little red ink. There is some doubt about the violet. It is a beautiful color, with strong contrast to the white background; but it sometimes tends to scale off after it has dried. Purple may be used instead; it is made by mixing red and blue inks.

When the chart has been inked, nail half-round wooden strips to the bottom and top edges (Fig. 2) and through the top strip bore 3/8-in. holes for the hooks shown in Fig. 1. The hooks are formed from 6-in. lengths of No. 14 iron wire.

A cloth chart, when not in use, should be rolled up from the bottom so that one may have quick access to the title to identify the chart. The number of the chart should also be placed where it can be read when the chart is rolled up. Cloth charts are so expensive that it is best to have a special storage cabinet to protect them. The rat- and mouse-proof cabinet shown in Fig. 3 will hold 200 charts.

COLOR SYMBOLISM

Much of the value of charts lies in their ability to give distinction and emphasis by the use of color. Do not employ too much color; that is, do not spoil the emphasis by overdoing it. Black ordinarily should be used for the less important parts of diagrams, and for explanations and development of equations. Use bright colors for emphasis, as of important parts of diagrams, stressed words in explanations, and key equations. Use different colors for distinction, as of different kinds of physical quantities, different component circuits in an electrical diagram, etc. When a letter designates a part of a diagram, or appears in a key equation, give it the same color as the part of the diagram to which it refers.

Insofar as possible, always use the same color for the same kind of physical quantity. The author has found the following system to be satisfactory. The abbreviations for the colors are: black, *bk*; orange, *or*; brown, *br*; red, *re*; green, *gr*; blue, *bu*; violet or purple, *vi*.

Vectors: horizontal components, *gr* or *bu*; vertical components, *or* or *br*; resultant, *re*; equilibrant, *vi*.

Mass, *bk* or *vi*; displacement, *br* or *gr*; velocity, *gr* or *vi*; acceleration, *or* or *re*; force, *re* or *bu*; work and energy, *bk*; arm of a torque, *bk*, *or* or *gr*; torque, *or* or *vi*; moment of inertia, *bk*; rotor for an angular quantity (such as torque), *gr* (the green arrow may be encircled by a red arrow-headed circle representing the angular quantity); area, *bk*; volume, *bk*; pressure, *or*.

Solids, *bk*, *br* or *vi*; mercury, *bu*; water, *gr*; stream lines, *gr* or *or*.

Fahrenheit, *bu*; centigrade, *re*; absolute, *or*; quantity of heat, *bu* or *vi*.

Waves: compression, *re*; rarefaction, *gr*; wave-fronts alternate *re* and *gr*.

Magnetic field lines, *gr*; pole, *re*; magnetic moment, *or*; permeability, *vi*; intensity of magnetization, *re*; magnetic susceptibility, *vi*; magneto-motive force, *re*; reluctance, *bk*; North, *re*; South, *gr*.

Electrostatic field lines, *or*; charge, *re*; quantity, *re*; positive, *re*; negative, *gr*; dielectric constant, *vi*; surface density of charge, *re*; potential, *br*; e.m.f., *br*; power, *bk*; capacity, *bu* or *or*; current, *re* or *vi*; resistance, *bk* or *re*; inductance, *gr*.

Optics: cross section of prism, etc., stippled in *bu*; ray, *or*, *gr*, or *re*; normal, *vi*; principal axis, *bk*.

The writer wishes to thank Professors J. O. Hamilton and E. V. Floyd, Mr. C. C. Brehm and Miss Jean Lyon for suggestions and assistance given in the course of his work with charts, and Professor W. R. Brackett, who assisted in the design and construction of the storage cabinet.

Physics in the Commerce Curriculum at the University of Cincinnati

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FOR a number of years the candidates for the degree of Commerical Engineer in the College of Engineering and Commerce of the University of Cincinnati have been required to take, in their third year, a course in general physics. The preparation of these students includes the differential calculus and a thorough course in general inorganic chemistry.

There are a number of reasons why a commerce student, who is fitting himself for an executive position in the business world, should include physics with such subjects as history, commercial law, banking, economics, accounting and statistics. Aside from the fact that, as an educated man, the business executive should have some knowledge of the science, he can hope to get something of the following from such a course:

1. Ability to read popular articles on invention and discoveries intelligently, to know to what field they refer and what types of problems are treated in that field.
2. Ability to discriminate between frauds and genuinely sound scientific advances.
3. Development of the powers of analysis and the habit of orderliness, characteristics of prime importance to the executive.
4. An understanding of the underlying principles of many industrial appliances.
5. Dexterity in the use of scientific equipment and an appreciation of its value.
6. A working knowledge of the metric system, of advantage in foreign commercial affiliations; plotting and reading of graphs, so useful in modern business.
7. Some preliminary training in laboratory work, should the student later decide to go into industrial research.

The theory part of the course consists of lectures and demonstrations upon the usual divisions of general physics, with special emphasis upon light and electricity. The class meets six times per week during the four-week periods when the men, on the "cooperative plan" of instruction, are in residence at the university. This schedule is equivalent to a three-hour course over a continuous period of eight months. The mathematics employed does not go beyond trigonometry and is used only when necessary for the statement of laws and the solution of problems. Wherever possible, attention is called to the *industrial developments* arising from the subjects under consideration, their economic significance, and the likelihood of further research upon the matter. The following topics are illustrative of the type of material studied:

Mechanics: velocity, acceleration, kinetic energy of automobiles; mechanical advantage; hydrometers; strengths of beams and wires.

Light: speed of light; theories of the nature of light; illumination problems; flood lights; mirrors and lenses; typical optical systems; uses of interferometry; optical rotation by sugar solutions; photoelasticity.

Heat: refrigerating and heating systems; thermal insulation; manufacture and uses of liquid air and "dry ice"; laws of cooling; application of the gas law to the calculation of a natural gas supply; heating values and costs of various fuels; factors affecting climate; relative humidity; thermal and luminous efficiencies of various sources of radiation.

Electricity and magnetism: effect of the invention of the compass on world trade; terrestrial magnetism research; interpretation of a hysteresis loop; communication based upon electromagnetic induction; principles of wireless transmission and reception; heating devices and lamps; determination of the cost of energy; ammeters and voltmeters, elements of a.c. and d.c. machinery; application of thermoelectricity in industry and research; neon tube and mercury arc lamp; electrolytic refining of metals; electroplating; primary and secondary cells; power transmission; the thunder storm, and lightning protection; applications of photoelectricity.

Sound: limits of audibility; elements of music; wave forms; speed of sound in various materials; vibrating strings and air columns; acoustics of buildings.

Besides the foregoing topics, lectures are given on the chemistry of photography, the determination of electronic charge, the Rutherford-Bohr hydrogen atom, isotopes, the measurement of v and e/m for an electron, the electromagnetic spectrum, x-rays, radioactivity, thermionics, and wave motion.

The experimental part of the course consists of sixteen periods of three hours each, the available experiments being as follows:

Mechanics: resultants of parallel and concurrent forces; free fall.

Light: laws of reflection and refraction; photometry; compound microscope; refracting telescopes; spectroscopy; diffraction grating; saccharimetry.

Heat: specific heat; heat of fusion; Joule's equivalent; thermal conductivity.

Electricity: plotting an electrostatic field; electromagnetic induction; thermoelectricity; inductance in a.c. circuit; Joule's law; model transmission line (*IR* drop); capacitance; construction of ammeter and voltmeter of a given range; Wheatstone bridge; characteristic curves of a three-element vacuum tube; laws of electrolysis.

Obviously no one student has time to perform all of the experiments, but he is expected to fill his entire working period with whatever ones most interest him. In the opinion of the students, the most *interesting* experiment in light is the one on spectroscopy, and the most *practical*, that on photometry. In electricity, electromagnetic induction ties with the radio tube as the most interesting experiment, and Joule's law is conceded to be the most practical.

Quizzes are given in the lecture course every two weeks, and in the laboratory course upon the completion of each division.

It is possible that in the future the course will be extended over a longer period of time and that more time will also be given to the laboratory. In 1934–1935 another course will be introduced for sophomores who are working for the degree of Bachelor of Business Administration. It will consist of three hours of lecture and one period of laboratory, extending through two winter terms and one summer. In keeping with the preparation of these students, the course will be less mathematical than that for commercial engineers.

Doctor I. A. Balinkin shares with the author the conduct of the commerce physics course.

Concerning the Program for the Pittsburgh Meeting

A special demonstration lecture on radiation and high temperature measurement, trips to the Westinghouse Research Laboratory, the Gulf Research Laboratory, and the Arnold Glass Plant of the American Window Glass Company, and a joint meeting with the American Physical Society for a symposium on heavy hydrogen are among the features planned for the fourth annual meeting of the American Association of Physics Teachers, to be held in Pittsburgh on December 26–29.

Of special interest this year will be the annual Science Exhibit of the A. A. A. S. and Associated Societies which will be held in the new building of the Mellon Institute of Industrial Research. There will be numerous exhibits from the many industrial research laboratories located in the Pittsburgh area, an unusually elaborate group of exhibits and demonstrations of equipment used in the investigation of neutrons, induced radioactivity, deuterium, cosmic rays and stratosphere phenomena, and a special series of demonstrations in modern physics arranged by Professor Charles T. Knipp and Professor J. B. Nathanson. Members of the American Association of Physics Teachers who have new and interesting laboratory or lecture-demonstration apparatus suitable for inclusion in the exhibition, should communicate with Doctor F. C. Brown, Committee on Exhibits, Smithsonian Institution Building, Washington, D. C. Free space will be provided for acceptable exhibits.

A part of the program will be devoted as usual to contributed papers. Members who desire to submit papers should send the titles as soon as possible to the secretary, Professor William S. Webb, Department of Physics, University of Kentucky, Lexington, Kentucky. The rules of the Association require that a copy of the paper or a 300-word abstract, be in the hands of the secretary not later than November 15.

Headquarters for the Association and the Physical Society will be in Webster Hall Hotel, which is located just across the street from the new Mellon Institute Building and within easy walking distance of the buildings of the Carnegie Institute of Technology and the University of Pittsburgh in which most of the meetings will be held. As far as possible, sessions of the Association and of the Physical Society that occur at the same time will be held in the same or neighboring buildings.

The members of the local committee for the Pittsburgh meeting are: Professor A. G. Worthing, *chairman*, University of Pittsburgh; Professor F. L. Bishop, University of Pittsburgh; Professor H. S. Hower, Carnegie Institute of Technology; Doctor L. O. Grondahl, Union Switch and Signal Company; Doctor L. L. Nettleton, Gulf Research Laboratory; Professor J. E. Rosenberg, Duquesne University; Doctor Dayton Ulrey, Westinghouse Electric and Manufacturing Company.

APPARATUS, DEMONSTRATIONS AND LABORATORY METHODS

On the Forces Between Magnets and the Law of Inverse Squares

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In the hands of Lord Kelvin the balance became an instrument of precision for the evaluation of electrical quantities by the direct comparison of forces and, although instruments of the balance type are still commonplace, the potentialities of the common balance in instruction courses do not appear to have been fully exploited. While Richardson[1] and others have developed a serviceable current measuring instrument, the use of the balance in quantitative magnetism, though not entirely overlooked,[2] has not received the attention it deserves. It is the object of this note to describe several experiments which, originally performed with the intention of providing a simple alternative to the more usual methods of "proving" the law of inverse squares, yielded results instructive from other points of view.

A hole was bored through the base of an ordinary non-ferrous laboratory balance to accommodate a special magnet holder (Fig. 1). One magnet was fixed to this holder and the force between it and a second magnet, placed on an adjustable table below the first, was measured by the alteration in the weight required to equilibrate the balance system.

Short magnets were employed and allowance was made for the forces acting on all the poles; this procedure, equivalent to applying known corrections, is considered superior to minimizing them at the expense of simplicity of experimental set-up. The magnets were of cobalt steel, 0.94 cm square, and 6.9 cm equivalent length, and were placed in one of the two positions shown in Fig. 1. The vertical forces between them in these positions are given by the equations

Position A,

$$m_1 m_2[1/(D-2l)^2+1/(D+2l)^2-2/D^2]=Mg, \quad (1)$$

Position B,

$$2m_1 m_2[1/D^2-D/(D^2+4l^2)^{\frac{3}{2}}]=Mg, \quad (2)$$

wherein M is the mass added to or subtracted from the pan according as those poles of the two magnets which are nearest each other are unlike or like. In the former instance we are concerned with unstable equilibrium which presents a difficulty in weighing. This was overcome by employing distance-pieces of ebonite which were placed between the magnets so that the balance was in its position of equilibrium: the excess weight required to remove the magnet from the ebonite cylinder was then determined. The difficulty experienced in measuring repulsions was in keeping the magnets in a vertical line when in position A and in a vertical plane when in position B. This arose only when the magnets were near together and in position A was overcome by placing them within a loosely fitting glass tube; the friction thus introduced did not appear to vitiate seriously the results obtained.

The magnets being of the same size and ma-

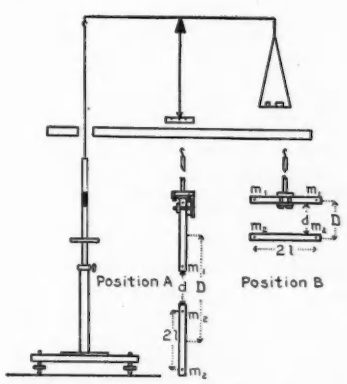

FIG. 1. Details of balance and magnet holder.

[1] L. F. Richardson, V. Stanyon and others, Proc. Phys. Soc. **41**, 36 (1928).

[2] See for example, R. G. Shackel, *A Modern School of Electricity and Magnetism*, Longmans, Green and Co., pp. 24–25.

terial and, according to a neutral point test, having approximately the same moment, we place $m_1 = m_2 = m$ (say) in Eqs. (1) and (2) and, having performed an experiment, evaluate the pole strength. Constancy in the value of m for different values of d indicates, in the absence of other factors discussed below, the truth of the law of inverse squares. To reduce arithmetical work the distance-pieces used in the attraction experiments were employed to fix the distances between the magnets in repulsion experiments and were subsequently removed.

(i) *Results for position A.* A typical series of results is shown graphically in Fig. 2 (a). Considering first the repulsion experiments, an apparent decrease in the pole strength of the magnets as they approach each other is to be noted. Considerations of the inverse square law apart, this may be attributed to inaccuracy in location of the poles (affecting the value of D) or to induction. Experiments were accordingly performed with *unlike* poles of the magnets adjacent, when it was found that the calculated value of the pole strength was reasonably constant over a larger range of values for d, thus indicating that the previous deficit may be attributed to induction. The apparent increase in the pole strength when $d < 1$ cm is, having regard to the rather high demagnetizing factor of magnets of the dimensions used, probably due to the fact that the magnets, being situated in each other's fields, are, by induction, more nearly saturated. It must also be borne in mind that at these small distances it is rather a question of the forces between pole faces, for which the formula $H^2A/8\pi$ is appropriate, than the forces between point poles.

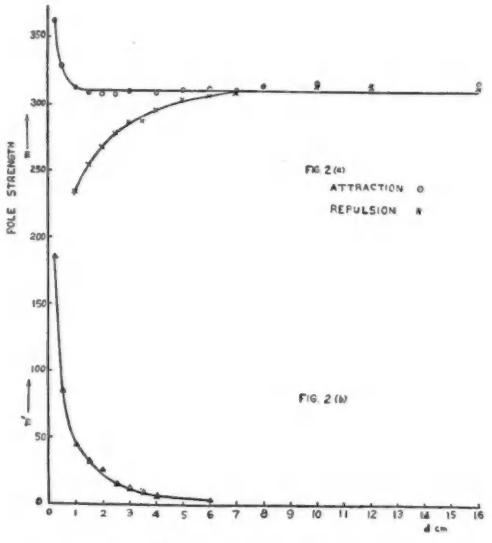

FIG. 2. (a) Relationship between m and d, for position A. (b) Relationship between m' and d, for position A.

(ii) *Results for position B.* See Table I. The explanations of the general trends in the values are similar to those given in the preceding results.

TABLE I. *Pole strengths deduced from results for position B.*

d (cm)	12	10	8	7	6	5	4	3.5	3	2.5	2	1.5	1	0.5
Repulsion	317	316	316	315	315	312	308	296	Magnets out of vertical plane.					
Attraction	312	315	316	319	320	324	329	330	333	337	339	346	354	379

(iii) *Experiments with demagnetized magnet in position A.* One of the magnets was demagnetized and the forces between it and the other magnet were measured for decreasing values of d. Assuming 312 as the pole strength of the magnet and replacing $m_1 \cdot m_2$ in Eq. (1) by 312 m', the value m' of the pole strength induced in the demagnetized magnet was calculated. The values obtained are indicated graphically in Fig. 2 (b). Unfortunately, as the magnetization is carried out in a non-uniform field, the first portion of a hysteresis curve cannot be drawn; and further, no correlation between m' and the difference between 312 and the corresponding observed pole strength in the repulsion experiments noted under (i) is to be expected as the measurements deal with different portions of the hysteresis curve.

A Working Model for Showing Nuclear Disintegrations

RICHARD M. SUTTON, *Department of Physics, Haverford College*

THE present interest in atom-smashing is ample justification for describing a simple and effective apparatus for demonstrating the attack upon the nucleus. If one can see the repulsion of α-particles by a mysterious nucleus, projected upon the screen of the lecture room, and can then watch the bombardment of the nucleus as the speed of the particles increases, one may obtain a vivid representation of the remarkable effects which have been produced in recent researches. Positrons, neutrons and protons may be ejected from this mysterious nucleus, and the process of atom-building by the capture of the original α-particles may be depicted.

The illusion is based upon the fact that a vertical projector gives no information about the *depth* of field but projects only a flat shadow of the field of view. A watch glass 5 in. in diameter is mounted in a box convex-side upward so as to cover the condenser lens, L, of a vertical projector, PM (Fig. 1). The "nucleus," mounted

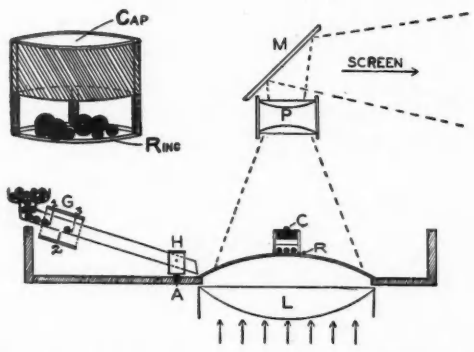

FIG. 1. Diagram of nuclear disintegration model. The smaller diagram shows details of the artificial nucleus.

in the center of the field at the topmost portion of the watch glass, consists of a small piece of 3/4-in. brass tubing standing on three narrow legs. The projection of this tube is a circle. It is fitted with an opaque cap, C, which can be removed to show "internal structure" of the nucleus after the surprising effect of a successful disintegration has whetted the curiosity of the observers. Inside the nuclear housing are placed a number of steel balls of two contrasting sizes (3/16 and 3/32 in.) ready to emerge as "neutrons" and "protons" when struck by the fast "α-particles." The projectile particles are 3/16- or 1/4-in. steel balls whose speed and direction of approach to the nucleus are controlled by rolling them one at a time through the inclined brass tube GH, which is pivoted with horizontal axis at H and vertical axis at A. A low initial speed starts the ball toward the nucleus; but because of the curvature of the watch glass, the ball rolls off the field of view in a delightful curved path, just as if it suffered an actual repulsive force from the spot in the center of the field of view. But as the speed of the incident particle is increased by giving the "α-ray gun" a steeper tilt, it acquires sufficient speed to dash into the nuclear housing, there to knock out neutrons and protons previously planted.

A number of fascinating effects may be observed: the original particle may be captured; it may disappear into the nucleus only to emerge an instant later after suffering wide angular "scattering"; it may eject a single neutron or proton; or it may cause a "nuclear explosion" in which three or four particles are ejected in different directions in one operation. The element of surprise is always present. A little practice with the α-ray gun will enable the operator actually to clip off individual nuclear particles. The author has tried various methods of concealing the balls inside the nuclear housing so that they will be discharged by the small impulses received from the projectiles. These balls may be slightly flattened on one side so that they will not roll freely until struck; or they may be poised in small holes cut in a flat piece of clear celluloid, fitted inside the housing. More successful than either of these methods, however, is the insertion of a very thin brass ring, R, between the watch glass and the housing so that its shadow coincides with that of the tubular housing. Thus, each emerging ball must climb a small hill before it starts rolling down the surface of the watch glass. Such a "potential barrier" is consistent with its electrical counterpart which is met in nuclear re-

search. This method of retaining the balls permits rapid recharging of the nucleus and it offers the further advantage that one may show the capture of the incident α-particles at a certain critical speed.

The effectiveness of the demonstration and its ease of operation are greatly enhanced by equipping the discharge gun with a simple escapement mechanism which releases each projectile ball individually, yet permits the gun to be loaded in advance with as many as 50 shots. Fig. 1 shows the details of the device. Each time the escapement gate, G, is raised, the sphere resting against vane 3 is released to descend the tube; at the same time vane 2 intercepts the remaining balls. Upon lowering the gate, vane 1 holds back the supply, allowing just one ball to descend from vane 2 to vane 3. The gun is then ready for the next shot.

There are a number of modifications of this type of atomic model, with "curved gravitational fields," which may be made with suitable variations of the treatment described here. The details of one such device, a model of the classic magnetic analyzer used for mass-spectrum work, will be presented in a later paper.

Demonstration of the Removal of Ions from Convection Currents

JOHN J. HEILEMANN, *Randal Morgan Laboratory of Physics, University of Pennsylvania*

THE fact that an ionized gas possesses the property of electrical conductivity is commonly demonstrated by passing the gases from a Bunsen flame between two plates, one connected to a charged electroscope and the other to ground. If a luminous flame approximately 2.5 cm high be placed about 15 cm below the plates, the leaves will quickly converge. If, on the other hand, the flame be placed the same distance from the plates but on a level with them, the leaves, if they come together at all, will do so slowly, showing that the ions have diffused and have thus come between the plates. With the flame kept in the same position, the leaves can be made to come together quickly by blowing, with the breath, the air above the flame into the space between the plates.

This property of discharging a conductor may be removed from the gas by allowing the gas to stand, by passing it through glass wool, by bubbling through water and by using the gas as a conductor of electricity.[1] Of these methods the easiest to demonstrate, and at the same time the most valuable from a pedagogic standpoint, is the last; namely, the subjection of the ionized gas to an electrical field established between conductors. For this purpose the arrangement shown in Fig. 1 may be employed.

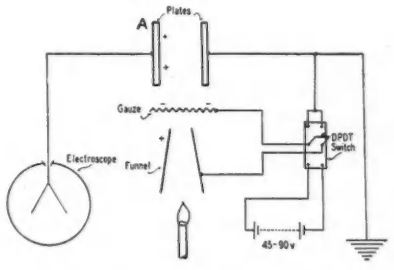

FIG. 1. Schematic diagram of apparatus.

A metal funnel is placed above the flame. Over the end of the funnel and about 1 cm away from it, is placed a copper gauze. The funnel and gauze are connected to a double-pole, double-throw switch, so that the former may be connected to a 90-volt battery in one position and to ground in the other. If the funnel, gauze and plate A are charged either as indicated in Fig. 1 or so that the plate and funnel are negative and the screen positive, the leaves will remain apart. As soon as the filter is removed by throwing the switch to the grounded position, the leaves begin to con-

[1] J. J. Thomson and E. Rutherford, Phil. Mag. **43**, 392 (1896).

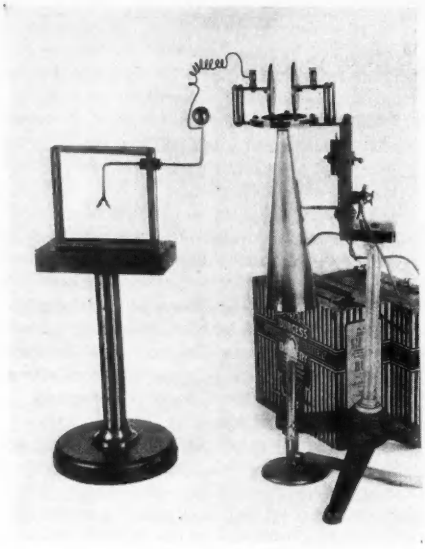

FIG. 2. "Ion filter" with projection electroscope.

verge. A photograph of the apparatus, built in the shop of this laboratory, is shown in Fig. 2. For classroom demonstration the electroscope is placed in a projection lantern.[2]

It is noticed that the electroscope is not protected when the gauze and the electroscope are charged alike. If the arrangement be thought of as analogous to a three-electrode vacuum tube, the gauze may be considered to represent the charged grid, which accelerates the ions of opposite sign toward itself. If this accelerating field be reenforced by the charge on plate A, as is the condition when the gauze and plate are charged alike, some of the ions will pass through the gauze and go to the plate, thus discharging it. The distribution of charge indicated in Fig. 1 is analogous to the condition existing in a vacuum tube, the grid of which has a sufficiently high negative potential to reduce the plate current to zero.

[2] J. J. Heilemann, Am. Phys. Teacher **2**, 28 (1934).

Personnel of A. A. P. T. Committees

The following appointments and changes in personnel of committees of the American Association of Physics Teachers have been announced by President Palmer:

Magnetic quantities: W. H. Michener, Carnegie Institute of Technology, *chairman;* Noel C. Little, Bowdoin College; Fred W. Warburton, University of Kentucky; David L. Webster, Stanford University; Marsh W. White, Pennsylvania State College; Samuel R. Williams, Amherst College.

Physics in liberal arts education: Calvin N. Warfield, Women's College of the University of North Carolina, *chairman;* Edwin Morrison, Michigan State College; L. W. Taylor, Oberlin College; Frances G. Wick, Vassar College; Lucy Wilson, Wellesley College.

Preparation in mathematics for college physics. Thomas D. Cope, University of Pennsylvania, has been appointed *chairman* to replace C. J. Lapp, who resigned. Other members are: Arthur A. Bless, University of Florida; Charles H. Dwight, University of Cincinnati; A. T. Jones, Smith College; Carl W. Miller, Brown University.

The ideal undergraduate curriculum. A. A. Knowlton, Reed College, has been appointed *chairman* to replace O. H. Smith, who resigned.

Membership. Homer L. Dodge, University of Oklahoma, *chairman.*

Differentiation in first year courses and *Visual education.* These committees have been discontinued.

Demonstration experiments in physics. A preliminary committee, consisting of John Zeleny, Yale University, *chairman,* H. W. Farwell, Columbia University, and Charles T. Knipp, University of Illinois, was appointed to consider the desirability and feasibility of having the American Association of Physics Teachers compile and publish under its auspices a book on "Demonstration Experiments in Physics." The committee reports favorably on both aspects of the project and states that several publishers have signified their willingness to undertake the publication of the proposed book.

DISCUSSION AND CORRESPONDENCE

On Acoustics for Students of Music

SINCE acoustics for students of music is a field which has been generally neglected, I think it is timely that I should add my experiences to those of Professors Stewart and Williams.[1] It seems to me from an experience of ten years that students of music derive much genuine profit from a brief course in acoustics. The value, however, cannot be extracted without the liberal use of arithmetic and the occasional use of very simple algebra, which in themselves afford the sort of thinking and practice needed by music students. Often this little glimpse of science is their only direct contact with things scientific. The scientific method of approach comes as a distinct surprise to these students. One finds that many of them have made an honest effort to understand something of acoustics by self-study; but, for example, what can they learn about quality of tone from a transverse wave delineation with its usual meager explanation or perhaps no explanation at all?

The type of presentation which is suitable for the usual physics lecture is far from convincing and is generally ineffective in a course of this kind. The lecturer, I find, must always keep in mind the musical experiences of the students, frequently making intimate comments on voice, orchestral instruments, tone combinations, intonation, etc. This means that he must have not only an especial interest in music but actual musical experience as a background.

Practically every effect studied should be shown by lecture demonstrations with plenty of time allotted for the discussion of each. The keynote of these demonstrations is simplicity. A good sound oscillograph seems indispensible, as it will illustrate interference, beats, simple quality, complex quality, tremolo, etc. but it should be regarded as a climax which requires extended preparation. Here is the important point: the students must undergo a patient preparation, simple but thorough, if they are really to profit by the study of acoustics; whether or not the result is successful depends mostly on the resourcefulness of the teacher during this preparatory period. The problem of sustaining interest will not simply take care of itself. In fact, the pedagogical treatment is of sufficient import to make a study of it profitable to students majoring in physics who may later be called upon to teach such work.

CLAUDE S. MCGINNIS
Department of Physics
Temple University

[1] Stewart, Am. Phys. Teacher **1**, 65 (1933); Williams, Am. Phys. Teacher **1**, 121 (1933).

Learning From Students*

THE suggestion that a teacher may learn from his students goes contrary to the traditions of our profession, for in the olden days the pedagog was regarded as a fountainhead of wisdom who, somewhat like the old town pump, gushed forth refreshing streams of knowledge to thirsty children. Nowadays, however, it is recognized that the teaching process is a cooperative one in which both instructor and pupil give and receive, and that each may learn something from the other.

The college teacher in his apprenticeship period usually begins by using the methods of those of his own instructors whom he has admired. Thereafter, by a process of trial and error, he gradually improves his techniques. In this process, he is at first helped by the counsel of older men, but after the apprenticeship has been served, years may elapse without a single visitor to the classroom who is trained in his specialty. In a vital sense, therefore, he is "on his own," and he must look about for tests of achievement. Unfortunately, the task of getting objective and valid criteria is so difficult that he may come to envy the physician whose failures are recorded in the cemetery, or the merchant whose successes stand proud and clear on the balance sheet. Even the minister, whose task resembles that of the teacher in complexity, can measure accomplishment, if he wishes, in terms of increased congregations or salary. It is true that the instructor may put his trust in examinations of his own devising; but, if he is critical, he may some day discover that succeeding generations of students have become acquainted with his foibles. The annals of the fraternity houses are often crammed with the questions of years gone by, and every sophomore knows, for example, that Professor Smithers always asks, in the final physics examination, for a statement of Newton's laws of motion.

A second very important method of self-measurement that is often used by the teacher, wittingly or unwittingly, is to note the effect of his teaching upon the students themselves. To the lecturer who is not too thick-skinned, the constant creaking of chairs is a hint that many students are not getting good value for their tuition fees. A more poignant signal is produced by whispering or open rowdiness. Further evidences of success or failure may come

* Written primarily for "The Pittsburgh Record," an alumni publication.

from unusually frank and open statements of students. These students tend to be of two classes: first, those who think very highly of the course; and second, those who are so vexed over some real or fancied wrongs that they are willing to risk lowered grades by challenging the methods of one who deems himself an expert. The great majority, however, are never heard from, and a teacher who tries to get criticisms by requesting them, face to face, is met by polite evasiveness. One might as well ask a neighbor for a judgment as to the manners of one's only child as to ask a sophomore to express his frank opinion, which may happen to be that the course is boresome or that the jokes were well worn in the days of Socrates. Knowledge of such opinions might indeed be obtained by disguising one's self as a freshman and "listening in" at fraternity house talk-fests, but such a method is hardly practicable.

For the teacher who really wishes to know what sort of person men say that he is, there is a very effective artifice that is used in certain colleges: the unsigned questionnaire and essay. Toward the end of the second semester the instructor explains his desire to know "the things that his best friends won't tell him." He urges the students to be as thorough as possible and to state both good and bad opinions quite freely. To promote frankness, they are requested to be very careful not to sign their names, and sometimes as an additional safeguard they are assured that the papers will not be read until the semester grades are turned in to the registrar. When this procedure is followed, the results are interesting and varied. In studying them, there is safety in numbers. Any one paper chosen at random might either lift the instructor to the highest heaven, or send his spirits down toward the inferno. A certain student states that the course has changed his entire attitude toward the world; a second that it is utterly useless and that the instructor is an unwieldly and stubborn ass. For the sake of one's comfort, a good method is to sort out the questionnaires according to the grades that the students indicate for the first semester's work. Then the teacher, beginning with the opinions of those who failed, and going through to those who were very successful, will have an experience like that of the trader in a rising market.

The questionnaires and the essays serve quite different purposes. The former give a broad and general view of the course, and the latter show what things are most prominent in each student's mind, and particularly the 'sore thumb' features that need correction. We have used both to excellent advantage in our department. A specimen questionnaire form is shown.

The results of this questionnaire for Physics I and II at our institution are interesting. This group is composed of about 170 students, mostly sophomores, who meet in several different sections taught by different instructors. If the results seem not highly reassuring, it should be remembered that most of those enrolled are premedical candidates and that many of them regard physics as the most difficult hazard of the grueling elimination contest that admits the winners to the medical school.

Since physics is a required course for most of these students, their *interest* is of considerable significance. In

QUESTIONNAIRE FORM

I. Kindly fill in the blank spaces and indicate in the margin the answers which are most nearly in accord with your unbiased opinions. Let your reply be as secret as possible, and above all do not affix your signature anywhere to this sheet. Your carefully considered reply will be helpful in the future conduct of this course.

1. ..... I have been most benefited by (a) demonstrations, (b) recitations, (c) problems, (d) laboratory work, (e) studying by myself.
2. ..... In comparison with other courses, I have found this course (a) highly interesting, (b) fairly interesting, (c) uninteresting.
3. ..... The demonstration lectures have been (a) very helpful, (b) slightly helpful, (c) not helpful, in understanding the subject.
4. ..... The recitations have been (a) very helpful, (b) slightly helpful, (c) not helpful, in understanding the subject.
5. ..... The problems section (if any) has been (a) very helpful, (b) slightly helpful, (c) not helpful, in understanding the subject.
6. ..... I have found the laboratory work (a) very helpful, (b) helpful, (c) not helpful, in understanding the subject.
7. My laboratory period: ———— day at ———— periods.
8. ..... I (a) have, (b) have not, been able, on occasions when I have sought it, to obtain reasonable individual help from my instructor.
9. My preparation for this course outside of class has amounted each week to about ———— hours.
10. My first semester grade in Physics ———— is ————.
11. ..... I believe that the system of grading used in this course is, as a whole, (a) very just, (b) fairly just, (c) unjust.
12. In the laboratory, experiments ———— have been most helpful in understanding the subject. (A numbered list of titles of the experiments accompanied this form.)
13. Experiments ———— have been least helpful.

II. Please write at least one-half page of frank, objective criticism, stating your opinions as to the good and bad features of the course.

1933, comparing it with other courses, 36 percent of those enrolled found it "very interesting," 56 percent, "fairly interesting," and 8 percent, "uninteresting." Several questions deal with the relative *usefulness* of the lecture-demonstration, the recitation and problem period, and the laboratory. In 1933, the results for the different parts of the course did not vary greatly; to each the highest or "a" rating is given by about 25 percent of the students, the lowest or "c" rating by 8 percent, and the middle or "b" rating by the remainder.

It is interesting to compare these results with those of 1932. Excepting the laboratory, we find 14 percent *fewer* students in 1933 give our course highest rating. The explanation may be that it has degenerated, or, on the other hand, that the students have changed. The writer believes that the latter is the case. In 1932 our students were more happy-go-lucky than in 1933. If they were refused admittance to our own medical school, they felt sure of entrance elsewhere. Last year, however, there was less money at home, less chance of professional success, and as a result a far more critically minded student body.

If this explanation is valid, the results for the laboratory are somewhat striking. In this division the percentage of students giving the 'a' rating *increased* about 7 percent. A plausible explanation is that after weighing student criticisms for the preceding year we rewrote our laboratory manual and eliminated several experiments that we, together with our students, believed to be hopeless. In this work, needless to state, we were assisted by ratings of experiments given in the questionnaires. We acted on the assumption that an experiment that is approved by none is

worthy of elimination, even though it is hoary with tradition.

Regarding the essays, it is difficult to give a fair account of the opinions, which were extremely varied. There was considerable pleasant persiflage, a slight trace of bitterness, and plenty of serious criticism both of personnel and methods. To interpret them adequately would need the service of a very wise and impersonal Arab. There was plenty of discussion as to why a premedical student should be required to study physics. Many showed a desire for a course requiring less thinking, one in which the memorizing of review questions given each week would insure an 'A' or 'B' grade. Above all, there was a manifest desire for an inflation of the currency; that is, an increase of the percentage receiving high grades. There was, through it all, a generous appreciation of the greatness of physics in modern times, and a friendliness toward the instructors. Not a single student impugned the sincerity or high purpose of any one of the staff.

We believe that teaching is and will always remain an art with no fixed criteria of success. Teachers will always learn by teaching, and in learning will be guided by the reactions of their students. The unsigned questionnaires and essays have, therefore, a real field of usefulness. We heartily recommend the experiment to all teachers who suspect that they might, like ourselves, learn something of value from their students.

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University of Pittsburgh

ANOTHER EXPERIMENT ON FORCED VIBRATION

THE article on forced vibration by I. Walerstein[1] prompts me to describe a similar but much smaller apparatus which I have used for several years to demonstrate various points in regard to forced vibration. A very small d.c. or a.c. motor with an external variable resistance in the armature circuit and with a heavy flywheel on its shaft drives a small eccentric (0.5 mm total motion) which operates a pivoted rocker (Fig. 1). To this rocker can be attached

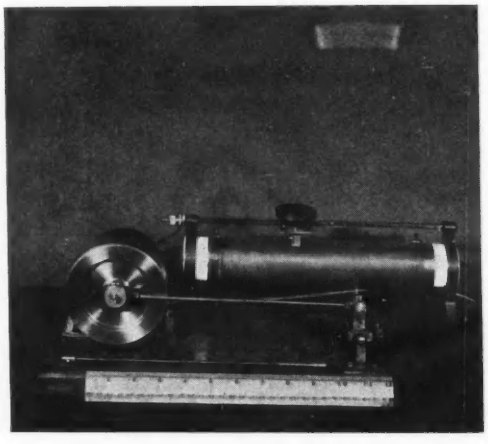

FIG. 1. Apparatus for demonstrating forced vibration. The vibrating rod is seen approaching resonance.

various metal rods 20–25 cm long. Small weights or damping vanes can be attached to the ends of the rods. Obviously the apparatus was designed to show the relations between the natural frequency without damping, f_1, the frequency with damping, f_2, and the resonant frequency f_3, where $2\pi f_1=\omega_1=\kappa$, $\omega_2=(\kappa^2-\gamma^2)^{\frac{1}{2}}$, $\omega_3=(\kappa^2-2\gamma^2)^{\frac{1}{2}}$; and also the relation for the amplitude,

$$A=C/[(\kappa^2-\omega^2)^2+4\omega^2\gamma^2]^{\frac{1}{2}},$$

where $\ddot{x}+2\gamma\dot{x}+\kappa^2x=C\sin\omega t$. In the ordinary case, $f_1=f_2=f_3$ (nearly) since the damping coefficient γ is small. When the forcing frequency is small compared with κ, $A_1=C/\kappa^2$. For the case of resonance, $A_2=A_3=C/2\gamma\omega$, or $A_2/A_1=\kappa/\gamma$; in other words, the amplitude at resonance becomes large when the damping is small.

These relations can be demonstrated readily with the apparatus. But perhaps the most striking effect is the inability of a small motor to speed up through resonance. As the operator decreases the series resistance the amplitude becomes large and the motor is held at a speed just less than that of the resonance frequency. But if the operator closes in on the top of the rod with his hands, thus reducing its motion to a few millimeters, the motor speeds up through resonance and thereafter at higher speeds the amplitude of the end of the rod is small. If now the operator increases the series resistance the motor slows down and as it approaches the critical frequency the load added by the large vibration causes the speed to drop very suddenly through that for resonance frequency.

If, while the rod is being driven by the motor, the operator plucks it at right angles to the driven direction the resulting Lissajous figure gives a ratio of the driven to the natural frequency. Near resonance the figure is an ellipse with rapidly changing direction of axes.

A phenomenon similar to the loading effect here described is in evidence when quartz plates or magnetostriction rods are placed in an appropriate electrical circuit. The large amplitude as the speed of rotation approaches resonance of some elastically constrained body is a phenomenon similar to that which has been experienced by those who have ridden in a small automobile of earlier days.

GORDON F. HULL
Department of Physics
Dartmouth College

December 11, 1933

[1] Am. Phys. Teacher **1**, 114 (1933).

Brief Notices of Recent Publications

First Year College Physics

General Physics. J. Joseph Lynch, S.J., Head of the Department of Physics, Fordham University. Pp. 254+x, Diagrams 211. Fordham University Press, New York, 1933. $2.00. "Intended as a set of lecture notes rather than as a textbook" for the course in general physics given at Fordham to meet the requirements for entrance to the Medical School. The selection of subject matter is along traditional lines. Medical applications are not emphasized.

Problems in College Physics. W. W. Sleator, University of Michigan. Pp. 56. Lithoprinted, paper cover. Edwards Brothers, Ann Arbor, 1934. $.70. A classified collection of 644 interesting problems, prepared for use in the general physics course and the course for engineers at the University of Michigan. The problems are well-chosen and are varied in nature; a number of them emphasize fundamental topics that ordinarily are not treated in the textbooks by means of problems.

Electricity. John Pilley. Pp. 348+xiv, Figs. and plates 181. Oxford University Press, New York, 1933. $2.50. A rational plan of electricity, both classical and modern, is presented in this book by a combination of inductive and deductive methods, and without the use of much mathematics. The author points out that "The disadvantage of abandoning the inductive order of presentation is not nearly so great as it would be if the claims of its more enthusiastic advocates were valid. Actually every scientific conclusion rests upon a much wider basis of fact than can ever be presented in a book, and this means that any attempt to follow the inductive order must involve adopting conclusions on inadequate grounds. So long, moreover, as only a limited number of facts can be presented, it follows that the conclusions to which they lead must already be suggested by the selection itself. This is not usually realized by the student, who is therefore given a much over-simplified conception of the work of scientific discovery. The original discoverer of any principle in science has no selection of facts to guide him; his discovery follows from the creative recognition that *as yet uncorrelated* facts provide a basis for a new principle. This being so, the claim so often made that the inductive method of presentation encourages an appreciation of the method and spirit of scientific inquiry rests on very insecure ground. Actually, the ability for original inductive thought is much rarer than is generally assumed by the advocates of the inductive method, and is shown only by minds possessed of a wide knowledge of experimental facts and of imagination of a particular kind. The only way in which it can be encouraged is no doubt through contact with a teacher himself possessed of it." This book is highly recommended as a reference book for both teachers and students of elementary physics.

Intermediate and Advanced Textbooks

The General Properties of Matter. F. H. Newman, Professor of Physics, and V. H. L. Searle, Lecturer in Physics, University College of the South-West of England. 2nd ed. Pp. 388+xiv, Figs. 113. The Macmillan Co., New York. $4.00. This revision of a well-known book is confined mainly to the correction of small errors which occurred in the 1928 edition.

Five Hundred Problems in Optics. Fred H. Perrin, Consulting Physicist. Pp. 37+iii, Figs. 3, Tables 7. Lithoprinted, paper cover. The Author, 272 Elmdorf Ave., Rochester, N. Y., 1933. $.90. A valuable, classified collection of problems, intended to supplement *The Principles of Optics*, by Professor Arthur C. Hardy and the author (McGraw-Hill). Considerable attention is given to such topics as resolving power and the theory of stops, color phenomena, sensitometry, tone reproduction and photographic optics. The author was formerly an instructor in the Massachusetts Institute of Technology, where many of the problems have been tested.

Physical Optics. Robert W. Wood, Professor of Experimental Physics in the Johns Hopkins University. 3rd ed. Pp. 846+xvi, Figs. 462, Plates 17. The Macmillan Co., New York. $7.50. A wealth of experimental details, invaluable to the research worker and useful to the teacher seeking new instructional experiments, has made this book a classic in its field. Only about 40 percent of the 1911 edition has been retained without rewriting and a large amount of new material has been added. There are new chapters on the origin of spectra, the Raman effect, and resonance radiation and fluorescence of atoms, molecules, solids and liquids. The illustrations are excellent.

History and Biography

Optiks: or, a Treatise of the Reflections, Refractions, Inflections and Colours of Light. Sir Isaac Newton. Reprinted from the 4th ed. Pp. 414+xxx, Figs. 57. McGraw-Hill Book Co., New York, 1931. $2.50. An exact reprinting of the edition of 1730, "corrected by the author's own hand, and left before his death with his bookseller." The printing and the reproductions of the diagrams are good. There is a Foreword by Professor Einstein and a 17-page Introduction by Professor E. T. Whittaker.

Great Men of Science. Phillip Lenard, formerly Professor of Physics and Director of the Radiological Institute in the University of Heidelberg. Translated from the 2nd Ger. ed. by H. Stafford Hatfield. Pp. 389+xv, Portraits 62. The Macmillan Co., New York, 1933. $3.00. Historical studies, varying in length from a paragraph to a number of pages, of 65 contributors to physical science, "chosen according to the originality and general importance of their

work, . . . the degree of inward and outward difficulty which . . . they had to overcome, and . . . the signs of intellectual greatness which we can recognize from the general character of their personalities." In the selection and treatment of the material there naturally is some evidence of the background and strong individuality of the author, who is the great pioneer of phosphorescence, cathode rays and the ionization potential. Yet the subject is approached critically and with understanding, and there is considerable new material and fearless evaluation of old material, based on an obviously extensive study of original sources.

Philosophy of Science

Guide to Modern Thought. C. E. M. Joad, Head of the Department of Philosophy at the University of London. Pp. 268+xi. Frederick A. Stokes Co., New York, 1933. $1.75. A book for laymen on the philosophical implications of modern science. There are chapters on nineteenth-century materialism, modern materialism, modern physics, current theories of life and matter, vitalism and creative evolution, abnormal psychical phenomena, psycho-analysis, and the invasion of literature by psychology.

Where Is Science Going? Max Planck, Professor of Theoretical Physics at the University of Berlin. Pp. 221. Translation and biographical sketch of the author by James Murphy. W. W. Norton and Co., New York, 1932. $2.75. A discussion of the principle of causality and the value of our knowledge of the external world, from the point of view of the non-positivist. Professor Planck assumes the independent existence of the external world and concludes that quantum theory cannot disprove the existence of causation in it. He criticizes many of the popular corollaries drawn from modern relativity.

Teaching Aids

Motion Pictures

This review is the first of a series intended to provide readers with reliable information concerning motion picture films available for use in physics instruction. Each review is based on an actual inspection and study of the film under conditions similar to those encountered in presenting the film to a class of students.

Sound Waves and Their Sources, 1 reel; **Fundamentals of Acoustics,** 1 reel. Harvey B. Lemon, Herman I. Schlesinger, Harvey Fletcher and Donald Mackenzie. 35 and 16 mm sound on film and 16 mm sound on disks. Erpi Picture Consultants, New York; University of Chicago Press, Chicago. Price each: 35 mm, $100; 16 mm, $50. Rental per day: 35 mm, $5; 16 mm, $3.50. The films were projected by the reviewer in a darkened lecture room equipped with a portable 35-mm projector. The first reel begins with animated diagrams of longitudinal waves in air from a tuning fork. The concepts of wave-length, frequency and amplitude are made clear. Simple and complex waves in a string and other sound sources are then shown in a very illuminating fashion with the aid of an animated oscilloscope. Particularly well done is the illustration of the mechanism by which the human voice is produced. The reel ends by showing how the quality of the voice depends on the structures of the head, throat and chest. Sound effects accompany the illustrations throughout and a running explanation of the important concepts lends much to the effectiveness of the picture. The second film deals with velocity, refraction and reflection of sound and the mechanism of audition. The functions of the various parts of the ear are clearly pictured and the range of audibility in both frequency and intensity is illustrated by a two-dimensional diagram. Several illustrations of attenuation and the effect of suppression of certain ranges of frequency are given. Reflection and absorption in rooms is illustrated with appropriate sound effects. These films are highly recommended for beginning physics. Perhaps in no other way can the fundamental ideas involved be so quickly appreciated by the student; the total running time is less than half an hour.

Walker Bleakney
Princeton University

Charts and Pictures

Microscopes. 1 chart, 27½×38 in. Central Scientific Co., Chicago. 5 cts. postpaid. Diagrams of two compound microscopes, monocular and binocular, with the course of the light rays shown in colors.

Wattmeter and Ammeter. 2 charts, each 16×17 in. Central Scientific Co., Chicago. 5 cts. postpaid. Charts of Weston instruments, one showing the interior and parts of an electrodynamometer type of wattmeter, the other, a movable iron type of a.c. ammeter.

Optical History Paintings. Bausch and Lomb Optical Co., Rochester, N. Y. Gratis to institutions. Three attractive reproductions of oil paintings, each mounted in a wall frame, 53.5×43 cm, ready for hanging. The subjects are Galileo's demonstration of his first telescope from the tower of St. Marks in Venice (1609), the discovery of bacteria by Van Leeuwenhock (1675), and Newton's demonstration of the prismatic solar spectrum.

Catalogs

Western Electric Vacuum Tubes for Use with Radio Telephone Broadcasting Equipment. Western Electric Co., Educational Director, 195 Broadway, New York. Gratis. Diagrams of the structure and wiring, and information on the use and electrical characteristics of various types of tubes.

DIGEST OF PERIODICAL LITERATURE

Contributors: R. J. Havighurst, F. E. Knowles, G. A. Van Lear, Jr. The Editor is responsible for unsigned articles.

Apparatus, Demonstrations and Laboratory Practice

Air resistance to falling spheres. E. V. Huntington; *Am. Math. Mo.* **40**, 451–455, Oct., 1933. If the resistance of the air on a sphere of weight W and of cross-sectional area A is assumed to be given by $R=kAv^2$, then, as is well known, the distance x fallen from rest in any time t is given by

$$x=(b^2/g)\log_e\cosh(gt/b), \qquad (1)$$

where $b=(W/kA)^{\frac{1}{2}}$. Hall has described a method for determining k experimentally [Proc. Am. Acad. Sci. **45**, 379 (1910)]. but an elaborate electrical apparatus must be used to measure t correct to 10^{-3} sec. In the present paper it is shown how k can be obtained with similar accuracy by a much simpler experiment which does not involve the measurement of time. Two spheres are dropped simultaneously and the distances x_1, x_2, traversed by them are measured with a steel tape; if 6-in. hollow spheres, one empty and the other filled with lead, are dropped 50 ft., one sphere will be several feet ahead of the other when it strikes the ground. By eliminating t between Eqs. (1), one obtains

$$\alpha^{\frac{1}{2}}\cosh^{-1}(e^u)=\cosh^{-1}(e^{\alpha\beta u}), \qquad (2)$$

where $\alpha=W_1A_2/W_2A_1$, $\beta=x_2/x_1$, and

$$u=kgA_1x_1/W_1. \qquad (3)$$

When Eq. (2) has been solved for u by trial and error, or by series, then k can be found by Eq. (3). The paper gives the solution of Eq. (2) by series.

The projection of laboratory experiments. Harriett H. Fillinger; *Educ. Focus* **5**, 24–27, 29, May, 1934. An ordinary opaque projection lantern can be used to make the details of many lecture experiments clear to a large class. A small ammeter or voltmeter which is being used in an experiment can be projected. The effect of light on silver chloride can be clearly exhibited. A surface tension effect can be shown by placing a little water in a large crystallizing dish and adding small bits of gum camphor. To demonstrate quickly the double refraction of Iceland spar, a colored plate of a bright line spectrum is projected and then the crystal of spar is placed over the colored lines. If a material to be projected is opaque, set it on a mirror placed in the lantern; if it is in solution and only color changes are to be noted, place it on white porcelain or paper.

Variable carbon resistance. A. G. Fruehan and C. L. Mehl; *J. Chem. Ed.* **11**, 187, Mar., 1934. A variable resistance, devised originally for use with a hot-wire glass cutter requiring 12 amp. on a 110-volt circuit, was made by cutting an old porcelain combustion tube, 1 in. external diameter, to the desired length on a carborundum wheel and nearly filling it with small pieces of graphite obtained by crushing old dry-cell electrodes in an iron mortar. Brass plugs were fitted loosely into the ends of the tube. Variations of resistance were secured by adjusting the screws, A (Fig. 1), which were mounted on a wooden

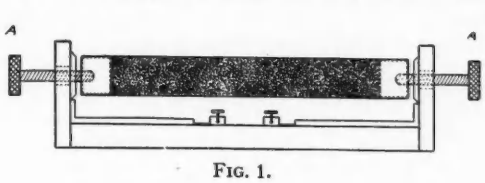

Fig. 1.

support. The screws, mountings, and milled heads were obtained from the legs of an old analytical balance. The milled heads were insulated with rubber. When used intermittently, the heat developed is not excessive.

Explosion hazard in coating mirrors. Jame C. Rice; *J. Chem. Ed.* **11**, 231, Apr., 1934. After having observed the violence of the explosion of a silvering bath, the author is led to suggest that recipe books publish warnings of the fact that concentrated solutions of ammoniacal silver, or moderately strong solutions when heated, are explosive. "All the constituents of the ammoniacal solutions of silver, made according to standard recipes, are capable of inflicting serious damage to the cornea. Silver ions are protein precipitants and the caustic alkali and the ammonia are, by virtue of their hydroxyl ions, escharotics."

Cooling effect of evaporation. A lecture demonstration. Alton L. Markley; *J. Chem. Ed.* **11**, 251, Apr., 1934. In this experiment on the cooling produced by the evaporation of ether, a simple method of disposing of the ether vapor is provided. A 260-ml, wide-mouthed gas-collecting bottle, almost half full of ether, is fitted with a stopper bored to hold a test-tube, which extends into the ether as far as possible, an inlet tube, which extends almost to the bottom of the bottle, and an outlet tube, which extends just through the bottom of the stopper. The inlet tube is connected to the gas jet, and the ether is caused to evaporate by bubbling gas through it. The outlet tube is connected

to a Bunsen burner where the mixture of gas and ether vapor is burned. If a thermometer and 5–10 ml of water are put in the test-tube, the water will freeze solid in 30 min. Data for a cooling curve may be obtained and recorded on the blackboard; undercooling, liberation of heat during crystallization, and effects of solutes on the freezing point may also be shown.

Rebuilding old storage batteries. RAYMOND BAVKULOO; *Pop. Mech.* **61**, 468–471, Mar., 1934. Lead cells may be rebuilt by removing and discarding the positive plates, and assembling two sets of negative plates to form the plates for a single new cell. The plates are straightened by clamping them between blocks. New separators are used when necessary. Dilute acid is used for repeated charge and discharge during the process of forming new positive plates. F. E. K.

A new laws of motion apparatus. HAROLD K. SCHILLING AND DAVID EICKHOFF; *Sch. Sci. and Math.* **34**, 34–38, Jan., 1934. A simple laboratory and lecture-room apparatus is described which can be used to test Newton's laws and to demonstrate that all freely falling bodies have the same acceleration regardless of their initial velocities. A 90-cm inclined track t (Fig. 1), consisting of two parallel metal

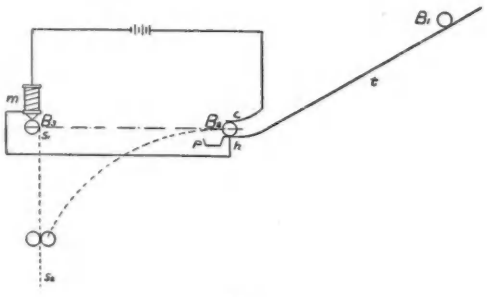

FIG. 1.

tubes, is provided with a short horizontal section h upon which rests a ball B_2. This ball is held in place by the clip c. An electromagnet m, which has a cone-shaped pole piece, is connected in series with points c and h. The magnet is so placed that the line of centers of balls B_2 and B_3 is horizontal. When ball B_1 rolls down and collides with B_2, the latter leaves the track and thus releases B_3. Balls B_2 and B_3 will collide in mid-air; B_1 rolls into the pocket p. The experiment can be varied by releasing B_1 from various points along t, by varying the distance between h and the magnet, and by tilting the whole apparatus in the plane B_2B_3 so as to give the initial velocity of B_2 a vertical component. In performing quantitative experiments, ball B_3 is dispensed with and a meter stick bearing a strip of red sensitized paper is clamped at S_1S_2 so that B_2 will strike it. The apparatus also makes a good exhibition or "museum" piece.

HISTORY AND BIOGRAPHY

Wilhelm Ostwald, the great protagonist. WILDER D. BANCROFT; *J. Chem. Ed.* **10**, 539–542, Sept., 1933; 609–613, Oct., 1933. An excellent account of the scientific activities of Ostwald, by one of his former students. Illustrated.

The evolution of the galvanometer. R. S. WHIPPLE; *J. Sci. Inst.* **11**, 37–43, Feb., 1934. The first use of the word "galvanometer" in English was apparently in a paper by Bischoff, published in 1802, in which the term was applied to an instrument similar to a gold leaf electrometer. Cummings, in 1821, was one of the first to apply the term to the instrument as it is understood today. The high sensitivity and quick action of the modern galvanometer have been due primarily to the reduction in mass of the moving system, although this in itself would have availed little if it had not been for the invention of the quartz fiber by Boys. Other factors in the development of sensitive instruments are the introduction of cobalt steel, with its high remanence, the greater purity of the materials in the conducting wires, the use of Bakelite varnish, etc. "The development of the valve as a measuring instrument has only just commenced. Galvanometers of the rectifier type such as the Moullin have shown that there are great possibilities in the development of such instruments." A bibliography accompanies the article.

The communication revolution, 1760–1933. ROBERT GREENHALGH ALBION; *Mech. Eng.* **55**, 531–538, Sept., 1933. The author, who is an associate professor of history at Princeton University, sketches the developments in communication and transportation methods since 1760 and discusses briefly their effects on the individual, on the spread of civilization, and on business, finance, politics and warfare.

The scientist and the historian: a plea for cooperation. B. MOUAT JONES; *Mem. Manchester Phil. Soc.* **76**, 19–30, 1931–32. Science as a factor in history, as distinct from the history of science, is a possible field of investigation which has been almost entirely neglected. When "we turn to the history books we find that, with scarcely any exaggeration at all, science has apparently played absolutely no part whatever in the drama of history. The scientist and his influence on the development of the life, thought and civilization of peoples are to all intents and purposes utterly neglected." Neither the scientist nor the historian "alone is capable of giving us histories in which science is afforded its right place." "Roughly, the scientist would provide the facts, and the historian would weigh them and estimate their significance in the general historic scheme, and give them their appropriate value and place."

Note on Gaede pumps. ANON; *Proc. Phys. Soc.* **45**, 743–744, Sept., 1933. This brief account of Professor Gaede's contributions to vacuum technique was published in connection with the announcement of the award of the

Duddell Medal in 1933. This medal is awarded annually by the Physical Society of London to an inventor of physical instruments of outstanding importance, or to a discoverer of new materials essential in their construction.

Physics Teaching and Science Education

The psychology of physics teaching. S. C. Garrison; *Peabody Reflector and Alumni News* **7**, 5–6, 21–22, Jan., 1934. The author is director of instruction and professor of educational psychology in Peabody College. Some of the most significant points of his article are as follows. (1) Every physics teacher may regard himself either as a teacher of students, as a teacher of physics, or as both. Actually, he is at least partly both in all cases. With students just beginning physics, it is important for the teacher to feel first of all that he is a teacher of students and that his duty is not to bring physics down to them but rather to take them as they are, and with their present knowledge, interests, and abilities, lead them on to the definite objectives of the course. High school physics should not seek so much to add to the stock of facts already possessed by the average student as to enrich and refine that already possessed. It should emphasize the *how*, the *why*, and the *how much* aspects of knowledge instead of the vaguer aspects secured under less well controlled situations. (2) Some of the aims of physics teaching are: (a) observing accurately significant facts and phenomena, and at the same time neglecting distractions and details that have no direct relation to the problem in hand; (b) developing a methodical plan of attack before beginning an experiment or set of observations; (c) using eyes, ears, and hands before consulting books, when knowledge of phenomena is sought; (d) maintaining system, order, and neatness in the arrangement of apparatus; (e) using care and intelligence in the manipulation of tools and apparatus, and endeavoring to acquire a good technique; (f) making measurements where quantitative knowledge is required, always carefully, intelligently, and as accurately as is demanded by the nature of the knowledge sought, but not more so; (g) making and recording calculations accurately and rapidly, using practical aids in computation; (h) maintaining accuracy and methodical procedure in arranging and tabulating data; (i) development of knowledges and appreciations centering around persons and experiments which have contributed much to the world; (j) development of knowledges and appreciations centering around the applications of physics for the advancement of human good; (k) development of knowledges and appreciations centering in the idea of the orderliness of the universe. (3) Studies made of the causes of success and failure in physics show that interest on the part of the student is the most important factor; this is one point where the teacher can well afford to exercise much effort and ingenuity. (4) One of the first problems of the physics teacher is to give more accurate meanings to the words which the student already has. This may be done through reading and class discussion, but it is questionable whether ideas secured in this way ever have the same functional value as those derived from experience with actual things where the student measures and tests relations and results. The former type of training leads to mere verbalism. Lists of technical words are of value to the teacher, so that he may be careful to see that the student secures such experiences from contact with laboratory exercises as will give proper meanings to these words. Their use by the students for the purpose of definition-learning apart from actual experiences with things is of questionable value. (5) Crudrup studied the records of 906 students in first-year college physics. About half of this group had previously studied high school physics but, for a given mental ability, they showed no superiority over the remainder of the group. Harvey has found that students who have not had high school physics obtain more accurate data and get better results in the college laboratory. A possible explanation is that in high school the textbook is emphasized and the laboratory work is rather incidental; the two methods seem to be incompatible, and will not mix very satisfactorily. (7) There is an urgent need for physics tests that will adequately measure student progress over a comparatively short interval of time and that will aid in diagnosing student difficulties.

A science survey. Ralph W. Hufford; *Sch. and Soc.* **38**, 276–279, Aug., 1933. The author has come to believe that the college science requirement for non-science majors should consist of a science survey course, given without laboratory, and covering about 10 percent of the time required for graduation. To make the course conform to the ideals which he outlines in the article, the author lays down some fixed rules for the course as follows: "(1) No field of science shall be presented that is not represented on the campus by a major department or school; (2) no professor shall conduct a division of the course whose major specialty is not in that field; (3) no part of the course shall be given by a professor who does not feel that he can give a fairly comprehensive survey of his science in such a way as to require an examination over what he has covered; (4) each lecturer shall prepare a syllabus of the ground covered, so that his colleagues in other divisions of the course will be informed as to the material covered by him; (5) no attempt will be made to make the course a continued story; on the contrary, each subject will be given as an entity; (6) credit will be given for the completed course, though each division will end with its own examination; (7) the grade in the course will be the average of the division grades." The author points out that such a survey course may have the following defects: "(1) Competitive major-seeking by some departments; (2) lack of enthusiasm on the part of some professors giving lectures in the course, and destructive criticism by others; (3) laxity in handling the course by some, thus making more difficult the work of others; (4) superficiality in treatment of the subject-matter, and underestimating the amount that the student can assimilate if pressed; (5) lack of uniformity in grading and examining." On the other hand he believes that there are several advantages. "(1) Each graduate will be slightly acquainted with all the sciences instead of having a bit more perfect understanding of a small part of some one field; (2)

the requirement of science will appear more reasonable to the average student; hence, his attitude toward the course should be more positive than it is toward the course he must take under the present system; (3) the quality of the regular introductory courses will be much improved by having none of the "requirement-meeters" in them, and classes being smaller, they should be better; (4) department overhead will be greatly decreased by elimination of the large and expensive introductory laboratory courses."

The scientific attitude and skill in thinking. ELLIOT R. DOWNING; *Sch. Sci. and Math.* **34**, 302–303, Mar., 1934. One must not confuse *scientific attitude* and *skill in scientific thinking*. By "scientific attitude" is here meant "that attitude of mind which impels one to attempt the solution of problems . . . by scientific thinking or good reflective thinking—rather than by the trial and error method. The scientific attitude is more than an intellectual assent to the proposition that the scientific method of thought is a desirable method of procedure. It is an impelling attitude and is therefore at least partially saturated with emotional elements." "One judges, then, how completely the scientific attitude dominates a man by noting in how far he has recourse to the scientific method in solving his problems." "But he may be quite unskilled in scientific thinking and so in nine cases out of ten reach wrong solutions. The success of his efforts depends on his skill in thinking, not on his scientific attitude." "To try to determine what are the elements and safeguards of scientific thinking by the questionnaire method is totally unscientific. Facts should be collected, not opinions. The writings of the great scientists, their records of procedure in the discovery and application of the laws of science, are the source materials from which this list must be determined by careful observation and analysis."

Laboratory fees. J. N. SWAN. *Science* **78**, 579, Dec. 22, 1933. Laboratory fees should be merged into general tuition, so that the students who wish to take science have an equal chance with those who wish to take other subjects.

Does science teach scientific thinking? ELLIOT R. DOWNING; *Sci. Ed.* **17**, 87–89, Apr., 1933. The author has devised a test of some of the elements and safeguards of scientific thinking which was administered to 2500 high school pupils. He found that pupils who had studied a great deal of science did no better on the test than pupils of comparable I. Q. who had studied very little science. If this was a valid test "the conclusion seems apparent that there is no evidence in the data given that high school pupils acquire skill in scientific thinking as a necessary by-product of the study of scientific subjects as at present taught." R. J. H.

Teaching the habit of scientific thinking. VICTOR H. NOLL; *Teachers' Coll. Rec.* **35**, 202–213, Dec., 1933. This is the second of a series of articles on scientific thinking. The first article, which appeared in the October, 1933 issue of this journal, analyzed the habit of scientific thinking into elements. The present article discusses possible ways of teaching scientific thinking. Conclusions are: that the natural sciences present some of the best though not the only materials for use in forming habits of scientific thinking; that the habits of thinking which constitute the scientific attitude should be taught and developed directly and in specific situations, and not considered as by-products of just any kind of teaching of science; that the habits of scientific thinking should be generalized and opportunity given for their practise in all possible situations. Suggestions of actual procedures to be used in teaching these habits are to be expected in succeeding articles. R. J. H.

SOCIAL AND ECONOMIC ASPECTS OF SCIENCE

The engineering economist of the future. DEXTER S. KIMBALL; *Elec. Eng.* **52**, 526–528, Aug., 1933. "The engineer who aspires to solve modern economic problems by applying his well-tried scientific methods, should take thought of the limitations of those methods; he must expect to do an unusual amount of studying before he can hope to replace old economic theories with others better suited to present conditions; and because of the capricious nature of the many variables involved, he should not attempt to predict future trends on the basis of past experience."

The machine—an aid to humanity. C. M. JANSKY; *Elec. Eng.* **52**, 532–535, Aug., 1933. "A history of the earliest discovery and development of machines is presented herewith as a simple and fundamental proof that machines are agents working for the benefit of humanity, and not, as so many are now maintaining, for man's harm."

The century of progress—what next? KARL T. COMPTON; *Mech. Eng.* **55**, 478–480, Aug., 1933. "(1) Research in pure science, engineering, and social science will receive increasingly greater attention, and ways will be found to make it more effective. (2) Society will exercise increasing control over business and industry to insure that the best interests of the public are to be served. This will inevitably include measures for stabilization of employment, control of production, and safeguarding of investments. (3) Technological education will be increasingly recognized as a most valuable preparation for a satisfactory life in this technological world, as well as the *necessary* training for that large special group who themselves develop, build, and operate the world's machinery. (4) Because of the engineer's responsibility, it is important that he have a more adequate sense of social responsibility and training to discharge humanitarian as well as technical responsibilities effectively, and these requirements will be reflected in modifications in the present methods of his college training."

GENERAL EDUCATION

Achievement tests in the social studies. E. F. LINDQUIST AND H. R. ANDERSON; *Ed. Record* **14**, 198–256, April, 1933. A good general discussion of objective tests

which would be of value to science teachers who are making such tests. Especially interesting is the discussion of the effectiveness of an individual test item. R. J. H.

Improving and evaluating the efficiency of college instruction. C. H. SMELTZER; *J. Ed. Psych.* **24**, 283–302, April, 1933. 523 freshman and sophomore students in a course in educational psychology were separated into an experimental group and a control group. The control group sections met five times a week for the usual informal lecture and discussion. In the experimental sections the work was divided into weekly units with a test each week and an intensive review and a further test for those who did not do well on the first test. The thirty percent of the students who scored highest on the first test were excused from the review and second test, which occupied one class period each week. Interviews were held with students in the experimental sections and on the day of review the instructor gave each student individual attention. An objective test covering the subject matter of the course was given to both groups at the start of the course and a similar test was given at the close of the course. The two groups were approximately similar at the beginning, and pairs of individuals from the two groups were matched. It was found that in the test at the close of the course the upper fourth of the experimental sections scored slightly higher than the corresponding group of the control sections, even though the students of the experimental sections had less classroom instruction than the similar group from the control sections. The lowest fourth of the experimental sections scored significantly higher than the corresponding group in the control sections, though both groups had the same amount of classroom instruction. The middle half of the students of the experimental group did somewhat better than the middle half of the control group.

R. J. H.

The effect of early entrance upon college success. CHARLES W. ODELL; *J. Ed. Research* **26**, 510–512, Mar. 1933. From data obtained from the complete high-school and college records of almost 2000 students who had attended a large number of different high schools and colleges, the author concludes that there are no grounds for believing that entrance to college when one or two years below normal age leads to undesirable results; students who do this maintain the higher marks which they were earning in high school and remain in college longer than do those who enter at the normal or an older age. "For those who are sixteen or seventeen he does not believe that the losses due to lack of social adjustment and other causes are in general sufficient to outweigh the evils of holding back individuals who are able and often eager to go ahead."

Honesty as a character trait among young people. H. W. JAMES; *J. Ed. Research* **26**, 572–578, Apr., 1933. From the results of tests and questionnaires administered to several hundred college and high-school students and teachers, the author concludes that: bluffing is generally practiced among college students; cheating in some form is practiced by most high-school students; it is a common practice for the majority of college women to lie to each other, to their parents, and to their instructors; factors other than honesty of a vocation are of most importance to college girls in their choice of a future husband's vocation.

Administrative recognition of teaching ability. JAMES C. CLARK; *J. Eng. Ed.* **23**, 764–765, June, 1933. The following quotations from this paper are of particular interest. "When one visits the laboratories of famous universities, hours are spent in looking at elaborate machines, delicate instruments, special facilities for research, etc. But nearly always I have come away disappointed, feeling that I had missed seeing that priceless thing, almost the only one that really counted, the spirit of the great teachers of such institutions in operation upon the minds and hearts of their students." . . . "Seemingly they [the presidents] are interested in anything and everything that will advertise the schools. Good teaching advertises a school of course, but why does not the quality of teaching interest administrators, especially since education is the main business of the universities? There are several important reasons why it does not, by far the most important of which is that it does not make a loud and immediate noise. It takes years for the results of good teaching to make a showing, and this is an age of ballyhoo and quick results."

Should courses in education be required of college teachers? SHELTON PHELPS; *Peabody Reflector and Alumni News* **7**, 3–4, 19–20, Jan., 1934. The author, who is dean of the graduate school of George Peabody College for Teachers, believes that the next step in the history of the teacher-training concept is the inclusion of courses in education as part of the preparation of prospective college teachers. He concludes from a survey of published studies and opinion that the balance of evidence seems plainly to be in favor of the idea and that the main points of disagreement at the present time are concerned with the contents of the education courses and whether they shall be required or elective.

GENERAL PHYSICS AND RELATED FIELDS

Protecting underground pipe lines against soil action. K. H. LOGAN; *Chem. and Met. Eng.* **40**, 514–516, Oct., 1933. As the result of an eleven-year study, the Bureau of Standards has concluded tentatively that corrosion of underground pipes is always an electrochemical phenomenon, the potential differences being the result of variations in oxygen supply at different points on the surface of the buried metal. Conductivity may be taken as a rough indication of the corrosiveness of a given soil. Corrosion may be reduced by the use of a bituminous, lead, zinc, cement-mortar, or vitreous-enamel coating, by keeping the pipe cathodic with respect to the adjacent soil, or by the use of a metal whose natural corrosion-products inhibit further attack.

The equation of state of a perfect gas. R. ROSEMAN AND S. KATZOFF; *J. Chem. Ed.* **11**, 350–354, June, 1934.

Clapeyron (1834) appears to have been the first person to arrive at a single formula connecting P, V and T; by combining the law of Boyle and Mariotte with that of Charles and Gay-Lussac, he derived the equation $PV=R(267+t)$, where 267 was obtained from the then accepted value of the coefficient of expansion, due to Gay-Lussac. It is not uncommon to find Clapeyron's equation of state "deduced by a vicious combination of Boyle's and Gay-Lussac's laws." Thus, in a recent well-known textbook of physiological chemistry, the "derivation" is given as follows: "$V=k_1/P$ (Boyle's law); $V=k_2T$ (Gay-Lussac's law); $P=k_3T$. (The last expression is a corollary of the first two laws; . . . .) Multiplying these together, $V^2P=k_1k_2k_3T^2/P$; $PV=(k_1k_2k_3T^2)^{\frac{1}{2}}=kT$." As an example of another derivation in which the equations of Boyle and Gay-Lussac are erroneously treated as being simultaneous, the authors cite the following: $PV=P'V'$, $PT'=P'T$, $VT'=V'T$; whence $(PVT')^2=(P'V'T)^2$, or $PVT'=P'V'T$. Three acceptable derivations are given in the paper; briefly, they are as follows. (1) A given mass of gas is changed from an initial state, P_0, V_0, T_0, to a second state, P_0, V', T_1, and then to a final state, P_1, V_1, T_1. For the first change one has $V_0/V'=T_0/T_1$; and for the second change, $V'/V_1=P_1/P_0$. By eliminating V' one obtains $P_0V_0/T_0=P_1V_1/T_1$. Similarly, for the same mass of gas changed to still another final state, P_2, V_2, T_2, one obtains $P_0V_0/T_0=P_2V_2/T_2$. Hence the general law. (2) In algebra it is proved that if P, V, T, are variables such that $V\propto 1/P$ when T is constant, and $V\propto T$ when P is constant, then $V\propto T/P$ when T and P both vary. (3) This method is the familiar one which involves the derivation and integration of the equation $dV/V+dP/P=dT/T$. It is pointed out that the three methods are not independent of one another.

Metric units of volume. ANON; *J. Sci. Inst.* **10**, 367, Nov., 1933. According to a recent announcement, the *milliliter* is to be employed as the unit of volume in all British Standards specifications prepared for use in the chemical industry. It is pointed out that the definition of the milliliter is independent of the units of length, and that the cubic centimeter is defined without any reference to the volume of a mass of water; hence the relation between the two can only be obtained by experimental determination. The difference between the two units "is so small, that it would appear, at first sight, to be a matter of complete indifference whether volumetric glassware were to be calibrated in terms of the cubic centimeter or the milliliter. Serious confusion, however, has been introduced through the misuse of the term cubic centimeter. Few students of chemistry or physics escape being misinformed that a cubic centimeter of water weighs 1 g and, conversely, that a cubic centimeter is the volume occupied by a quantity of water which weighs 1 g." These statements would not have been true even if the kilogram had been accurately constructed in accordance with its original definition, for 1000 cm³ of water would have weighed 1 kg only if at 4°C and in vacuum, conditions under which the weighing of water is clearly impracticable. Actually, water at 15°C and having an apparent weight in air of 1 kg has a volume of nearly 1002 cm³.

The biology of heavy water. G. N. LEWIS; *Science* **79**, 151–152, Feb. 16, 1934. When placed in heavy water, tobacco seeds failed to germinate, micro-organisms failed to grow, and the rate of fermentation by yeast was greatly inhibited. Flat worms became inactive after two hours; after four hours half of them failed to revive when returned to ordinary water. A little heavy water fed to a young mouse caused distress, but not death. It is concluded that highly concentrated heavy water inhibits vital processes but that it is not greatly toxic.

How rare gases give beauty to lighting. A. P. PECK; *Sci. Am.* **149**, 15, 155, Oct., 1933. A "neon" tube does not always contain neon. Argon, with mercury as a catalyzing agent, is used to obtain a blue color. A blue color in an amber tube gives green. Helium gives white approximately. Helium in a yellow tube gives a golden color. The electrodes are made of a secret alloy that does not decompose or emit particles.

What is a fifty-pound weight? RALPH W. SMITH; *Sci. Mo.* **38**, 111–117, Feb., 1934. This question is taken as the point of departure for a discussion of the origin of the American system of weights and measures which leads back to the beginnings of recorded history and incidentally throws light on the origins of some of the anomalous terms and abbreviations (e.g., lb.) occurring in metrology. The question is answered thus: "A fifty-pound weight is an object, usually of metal, having such a mass that, when compared in air under specified conditions, the gravitational force acting upon it is just fifty times as great—within appropriate tolerances, of course—as the gravitational force acting upon a standard mass of specified characteristics known as the 'pound,' which is equal to 0.4535924277 kg." The author is chief of the Section on Weights and Measures Laws and Administration of the National Bureau of Standards. G. A. V.

Atoms. PAUL R. HEYL; *Sci. Mo.* **38**, 493-500, June, 1934. In addition to the early fruitless speculations of the Greeks, the development of four lines of evidence for the atomic theory of matter are traced. These are: the general facts concerning the expansibility of gases, change of volume accompanying vaporization, etc.; chemistry; Brownian motion; electrical discharge phenomena. The third and fourth of these lines are discussed in considerable detail, and there is included an illuminating and entertaining account of Brown's attempts to coordinate the observed motions with phenomena of life, which culminated in his observing them in material taken from the Sphinx. G. A. V.